Transitioning Science Teachers to an Inquiry-Based Approach to Develop Critical Reasoning Skills in High School Students

by

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ABSTRACT

To develop critical reasoning skills potentially advances students' ability to critically consume information, make informed decisions, and actively participate in a democracy. An inquiry-based pedagogical approach to science teaching remains an effective means to develop critical reasoning skills. Participating in scientific inquiry requires students to generate arguments and test alternative hypotheses using experimental evidence. Scientific inquiry demands that students use their critical reasoning skills. Unfortunately, many teachers fail to allocate an adequate amount of time for genuine experimentation in science classes. As a result, science classes often leave students unprepared to think critically and apply their knowledge in a practical manner.

The focus of this study was to investigate the extent to which an inquiry-based professional development experience, including a two-day summer workshop and 18 weeks of follow up Professional Learning Community (PLC) support, affected the attitudes and pedagogical skills regarding scientific inquiry among six high school biology teachers. A concurrent mixed methods, action research design was used to measure changes in teachers' attitudes, perceptions, and skills regarding inquiry-based pedagogy was measured throughout the 22 weeks of the study. A survey instrument, card sorting activity, classroom observations using the Reformed Teacher Observation Protocol (RTOP), individual interviews, and PLC observations were used to gather data. Results indicated the professional development was effective in transforming the participating teachers' attitudes, perceptions, and skills regarding inquiry-based pedagogy.

DEDICATION

For John, Natalia, and Dominic, Mom and Dad, and Grandma and Grandpa Buettner.

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CHAPTER 1

BACKROUND AND CONTEXT OF THE RESEARCH

"Our species needs, and deserves, a citizenry with minds wide awake and a basic understanding of how the world works." Carl Sagan

Problem

Science education is a vital space in which students may develop valuable reasoning skills that allow them to think critically and solve fluid, everyday problems (Bao, Cai, Koenig, Fang, Han, Wang, & Wu, 2009). Unfortunately, time spent engaging in the type of scientific exploration that will develop critical reasoning skills in high school classes has been replaced by a focus on imparting content knowledge, and a direct instruction method of teaching is now widely recognized as normal, traditional science instruction (Anderson, 2012). Direct instruction focuses on developing students' declarative knowledge about specific facts and concepts that we know, rather than focusing on developing students' problem solving and critical reasoning skills (Lawson, 1988; Anderson, 1980). As a result, many students leave high school without experiencing scientific inquiry in a way that would contribute to the ability to think critically (Perie, Grigg, & Donahue, 2005). A survey instrument designed to measure the extent to which high school students have acquired critical reasoning skills, the Programme for International Student Assessment (PISA), demonstrated 69% of high school graduates in the United States are unprepared for college-level science (OECD, 2012). Further, in all countries surveyed, problem-solving abilities varied dramatically between schools, including schools that had similar performance in other areas (OECD, 2012). This disparity suggests that the development of skills required for solving problems depends on teachers who embrace and effectively implement inquiry-based pedagogy (OECD, 2012).

A considerable amount of research has been conducted and reviewed to support the notion that inquiry-based teaching methods effectively promote the development of scientific reasoning abilities (Adey & Shayer, 1990; Bao et al., 2009; Gerber, Cavallo, & Marek, 2001; Lawson, Abraham, & Renner, 1989; Lawson, 1995, 2010). An inquiry-based approach aims to develop scientific literacy, which involves both content acquisition and process skills development (Lawson et al., 1989). Generally, courses that follow an inquiry-based format introduce each unit through the presentation of something puzzling that leads students to ask the question, “why?” Subsequently, time is allocated for students to generate multiple possible explanations for what they observed, design and conduct controlled experiments, and then collect data, discuss results, and finally draw conclusions (Lawson et al., 1989; Lawson, 2010). Studies that examine the effectiveness of an inquiry-based approach consistently demonstrate superiority when compared to direct instruction in developing reasoning skills and transferring reasoning skills to other areas of curricula (Renner, Stafford, Coffia, Kellog, & Weber, 1973; Bowyer, 1976; McKinnon & Renner, 1971; Renner & Lawson, 1975; Carlson 1975; Lawson et al., 1989). Further, inquiry-based science instruction produces significant gains in attitudes and motivation towards science, as well as self-concept in the areas of intellect and school status (Brown, 1973; Allen, 1973; Malcolm, 1976; Lawson et al., 1989). As the abundant body of research suggests, an inquiry-based approach is the optimal way to teach science or any subject matter where concept acquisition is the goal (Lawson et al., 1989).

Problem of Practice

Here in Arizona and at my own school, where I teach and serve as the science department chair, many students are leaving high school without experiencing scientific inquiry in a way that contributes to their ability to think critically. In the years leading up to the present study I witnessed a decline in the frequency of the science teachers in my department doing laboratory activities in class that enabled students to employ genuine curiosity, creative thinking, problem solving, and critical reasoning skills. When I visited classrooms, it was evident that many teachers organized the curriculum in a relatively traditional, direct manner, focusing on the acquisition of specific facts concepts (Lawson, 1988; Anderson, 1980). In many cases, units began with students spending time taking notes to prepare for a deeper understanding and application of the concept. Teachers typically presented notes using PowerPoint or Prezi, and introduced terms followed by definitions. Further, during the laboratory activities, teachers regularly distributed instructions for students and preceded labs with demonstrations of what to do as well as a description of what outcomes to expect. Although this method introduced all of the necessary material, the process failed to elicit critical thinking skills among the participating students.

Preliminary data collected through observations and interviews I conducted in a previous action research cycle during the spring of 2016 revealed factors that may be responsible for such a large number of teachers reverting to a more traditional teaching style in the years leading up to the present study. The data suggested that increasing pressure from administrators to demonstrate evidence of specific standards being covered in lesson plans and curriculum guides, as well as district collection of common assessment data, caused many teachers to feel as though they were being pulled in two directions (Biology Teacher, personal communication, February 3, 2016). Teachers described feeling a pressure to adhere to standards and district initiatives that conflicted with a desire to teach in a manner that facilitates the development of critical reasoning skills (Biology Teacher, personal communication, February 3, 2016). Teachers also expressed feeling that there was a lack of resources, support, training, and mentoring for inquiry-based teaching (Biology Teacher, personal communication, March 24, 2016).

Over the last four years, district level administrators steadily increased accountability measures to increase student achievement. The administrators maintained that assessing students throughout the year on their comprehension of the State Standards in each of their core subject areas allowed specialists at the district level to collect data that would facilitate discussion between teachers and allow them to make adjustments to programs, curriculum, and instruction. Unfortunately, as teachers across the district have transitioned to this top-down accountability model, I witnessed many of my colleagues become extremely frustrated and exhausted (Biology teachers, personal communication, April 6, 2016). Teachers felt as though they did not have enough time to cover all of the required material to spend class time engaging in genuine experimentation and discovery (Biology teachers, personal communication, April 6, 2016). The district initiatives also caused teachers to feel they were being micromanaged, losing their creative freedom, and being required to teach an unreasonable amount of information. Rather than building professional capital as suggested by Fullan, Rincon-Gallardo, & Hargreaves (2015), our district guidelines unintentionally perpetuated an inefficient external accountability model (Mourshed, Chijioke, & Barber, 2010). Collectively, this situation led many teachers to revert to a more traditional teaching style and left a sense of cynicism among even the brightest and most enthusiastic instructors (Biology teachers, personal communication, April 6, 2016).

Importance

Taken together, this information suggested the need for support for teaching via scientific inquiry. An inquiry-based approach to teaching focuses on developing reasoning skills used to generate arguments and test alternative hypotheses using experimental evidence. These arguments and evidence are the essence of scientific literacy and establish the foundation for effective thinking in virtually all professions (Lawson, 1995, 2010). Through this work, research suggests that students will be better prepared to think critically and solve the problems of the future, and may even be more inspired to pursue careers in technical fields (Adey & Shayer, 1990; Bao et al., 2009; Gerber, Cavallo, & Marek, 2001; Lawson, 1995, 2010).

CHAPTER 2

THEORETICAL PERSPECTIVES & RESEARCH GUIDING THE PROJECT

As described in Chapter 1, many of the science teachers in my department struggled to incorporate laboratory activities into their instruction that allowed time for students to engage in creative thinking, problem solving, and reasoning. The bodies of literature that informed my thinking about this issue and how to address it were: constructivism, experiential learning theory, research about inquiry-based professional development programs, and adult learning theory. Constructivism and experiential learning theory provided support for inquiry-based science instruction as an effective pedagogical strategy. These theories, as well as research about inquiry-based professional development programs and adult learning theory, also informed the design of the study.

Constructivism

When constructivism was initially developed in the 1930s, it was quite unconventional, and has remained that way to a certain extent because it conflicted with the traditional, generally accepted approach to education that still persists today (Von Glasserfeld, 1996). Jean Piaget was incontrovertibly the pioneer of this approach, which required radical changes to long held concepts about education and knowledge (Piaget 1937, 1967, 1970; Von Glasserfeld, 1996). Piaget considered cognition a biological function that was an instrument of adaptation, and believed that the purpose for this function was the construction of conceptual structures. As a result, in this view, knowledge was seen as the result of individuals' physical or mental activity (Von Glasserfeld, 1996; Piaget 1937, 1967, 1970). According to Piaget, cognitive change and learning took place when an observed phenomenon produced surprising results, which created an uncomfortable sense of disequilibrium with previously held notions (Von Glasserfeld, 1996). This eventually led to a new understanding of the phenomenon, along with a new cognitive structure and a restoration of equilibrium as the new knowledge was reconciled with previous understanding (Von Glasserfeld, 1996). This view strongly conflicted with conventional notions of knowledge and the way it was acquired. No longer could knowledge be viewed as the simple accumulation of facts and concepts from books and teachers; in contrast, Piaget had suggested that true knowledge had to be experienced first-hand. This shift in understanding suggested a necessary change in the structure of educational organizations and instructional strategies.

John Dewey was also an important contributor to the development of constructivism in education. In contrast to a traditional approach to education, Dewey made a case for designing curriculum that centered on the student (Kruckeberg, 2006). He continuously referred to the notion that genuine education was a result of experience, and students needed to be active constructors of their own knowledge (Dewey, 1938). More specifically, Dewey (1938) believed learning was dependent on students experiencing problems first-hand that evoked a curiosity that led to a quest for answers and produced new ideas. Newly acquired facts and ideas could then become the foundation for solving new problems in different settings. This approach was similar to Piaget's in the sense that student experiences were a critical focus for education (Kruckeberg, 2006).

In the field of science education, constructivism refers to the idea that students should be actively engaged in answering puzzling scientific questions (Brown, Collins, & Duguid, 1989; Capps, Crawford, & Constas, 2012; Dewey, 1938; Schwab 1976). The inquiry-based approach to science teaching was informed by constructivist perspectives. In the inquiry model, students must have experienced something puzzling, which led them to experience disequilibrium, ask questions, search for answers, design and conduct experiments, and then assimilate their newly found knowledge to new cognitive structures along with existing understanding (Lawson, 1988, 1995).

Many educational professionals have felt threatened by the constructivist view because the traditional conception of teaching has been that teachers tell students about *truths* of the real world (Von Glasserfeld, 1996). By comparison, under the constructivist view, teachers would have lost some of their authority, as the center of knowledge shifts from teacher to students. As a result, many schools and educational organizations have clung to a more traditional approach, emphasizing the memorization of facts to pass tests and earn diplomas, rather than learning to think critically and solve problems in new contexts. Consequently, there was much opposition to the notion that a constructivist philosophy be used as a lens to develop and encourage innovative science teaching methods (Von Glasserfeld, 1996).

Experiential Learning Theory

Proponents of experiential learning theory (ELT) built on the work of constructivists like Piaget and Dewey, and viewed learning as a process that was actively constructed by the student through direct experience. Similar to constructivism, ELT required relearning and the resolution of conflicts between longstanding notions of how the world works and exposure to new concepts and theories. Proponents of ELT claimed that for real learning to take place, students must progress through entire learning cycles of experience, reflection, thinking, and action (Kolb & Kolb, 2005). According to Kolb

(2014), the laboratory method for ELT involved an experience followed by data collection, analysis, and modification of behavior. Moreover, immediate concrete experience served as the foundation for reflection and learning. Personal experience provided the groundwork for learning because it provided the opportunity for students to find personal meaning in otherwise abstract concepts, and also provided a reference point for testing ideas that arose during the learning process (Kolb, 2014).

The ideas presented in ELT have clearly been connected to science teaching, as the spiral structure of experience, reflect, think, and act mirrored the process of scientific inquiry. In science education, the term *learning cycle* aligns with the process of scientific inquiry and has come to refer to a three-step process of teaching science: exploration, term introduction, and concept application (Lawson, 1995; Lawson et al., 1989; Renner & Marek, 1988, 1990). The exploration phase in this model has afforded students time to investigate new phenomena so they were prompted to ask questions they attempted to answer through hypothesis generation and experimentation. Term introduction occurred *after* the investigative phase and allocated time for the teacher to attach terms to the newly discovered concepts. Finally, concept application provided time to challenge students to apply these new concepts in different contexts (Lawson, 1988; Musheno & Lawson, 1999). Research results have shown the learning cycle model to be an effective method for science instruction because it facilitated critical and creative thinking, promoted better understanding of scientific concepts, and fostered higher order reasoning skills (Lawson, 1995; Musheno & Lawson, 1999).

Although the learning cycle traditionally has a more specific meaning in science education as compared to general educational theory, the underlying principle of learning through experience is common to both. The presence of research in support of teaching using a learning cycle format strengthens the argument in favor of an inquiry-based approach to science teaching (Brown et al., 1989; Capps et al., 2012; Dewey, 1938; Schwab, 1976; Lawson, 1995; Lawson et al., 1989; Renner & Marek, 1988, 1990).

Constructivism, Experiential Learning Theory, and Inquiry-Based Professional Development

The ideas presented in constructivism and ELT are not limited to young learners; they apply to learners of all ages. Characteristics of effective professional development (PD) for teachers are well researched. Results indicated common features among the most successful programs included (a) modeling teaching strategies, (b) engaging teachers in inquiry-based experiences, and (c) connecting PD to work that can be taken back to the classroom (Capps et al., 2012; Darling-Hammond & McLaughlin, 1995; Desimone, 2009; Loucks-Horsley, Hewson, Love, & Stiles, 1998). Few studies have been conducted that actively engaged teachers in authentic inquiry experiences, where their PD was conducted in conjunction with scientific research. However, Capps et al. (2012), discovered that unlike many typical inquiry PD studies, studies that incorporated authentic experience into PD related to science were very successful. These studies indicated that first-hand experiences helped the teachers better understand the process of scientific inquiry and more successfully integrate the process into their own classrooms (Capps et al., 2012). To successfully teach science through an inquiry-based approach, research has shown that teachers needed to have enough familiarity and training with scientific inquiry themselves, to be able to translate their experiences into inquiry-based experiences for their students (NRC, 1996; Westerlund, Garcia, Koke, & Mason, 2002).

Thus, one professional development method that researchers recommend is to have teachers participate in genuine scientific research (NRC, 1996; Westerlund et al., 2002).

This approach is consistent with constructivist and ELT perspectives because scientific experimentation immerses teachers in the culture of science and actively engages them in activities that involve asking questions, learning laboratory techniques, analyzing data, interpreting results, and solving problems, which allows for the construction of knowledge through reflection, critical thinking, and practice. Just as Piaget and Dewey advocated for learning within relevant contexts, researchers studying inquiry-based PD found that teachers learning about teaching inquiry-based science by learning scientific knowledge through inquiry themselves, learned to think differently about how to approach science teaching (NRC, 1996; Westerlund et al., 2002).

Inquiry-Based Science Professional Development

Westerlund et al. (2002) conducted a study of 23 secondary education teachers of varying experience levels who participated in an eight-week summer research program and then investigated the effects of the experience in their classrooms during the following school year. The researchers intended to test whether authentic research experiences promoted more inquiry-based science teaching. The teachers participated in a summer program called the Science/Math/Technology Education Institute (SMTEI) program, based on the program developed at Southwest Texas State University. In this program, teachers worked in laboratories of scientists who shared their interests. During that time, teachers maintained journals, and participated in interviews with the scientists. The teachers also participated in evaluations and created activities that they planned to carry out with their students during the school year, and presented the results of their research to the other participants and researchers as a culminating activity. The teachers also took pre- and post-test assessments of scientific knowledge at the beginning and end of the summer program, and then their efforts in incorporating scientific inquiry into their lessons were tracked during the following academic year through classroom observations and meetings (Westerlund et al., 2002).

The results of the study indicated that the summer research experience successfully taught teachers about inquiry (Westerlund et al., 2002). The vast majority of teachers applied their summer research experience to their classrooms and all of the teachers involved in this program improved scores on their scientific knowledge tests; the average gain was 28%. As a whole, this study suggested a summer research experience was an effective way to conduct professional development for science teachers learning inquiry-based science teaching methods.

Radford (1998) also studied the effectiveness of a program called Project LIFE, which involved a three-week summer course, four weeks of work on an independent research project, and academic follow-up workshops for improving teachers' science content knowledge, reasoning skills, attitudes toward science, and teaching methodologies. The teachers who participated in this study ranged from upper elementary to high school and varied in terms of experience level. The researchers conducted the summer course in university labs and a nearby park, where a variety of habitats could be studied. Teachers acted as scientists and were engaged in genuine hypothesis generation, experimental design, and data collection. Throughout the experience they kept learning logs and journals that provided opportunities for teachers to apply the new skills they had learned to novel situations and reflect on their practice. In the four weeks following the summer course, teachers designed and conducted independent science investigations that could be used in their classrooms. Additionally, academic year support consisted of five-daylong workshops to support teachers' efforts at integrating what they learned in the summer into their curriculum.

The data collected by Radford (1998) suggested students who had teachers who participated in Project LIFE had significantly higher scores on processing-skills achievement tests and more positive attitudes toward science than students who did not have teachers who participated in the workshop. Teachers successfully integrated activities from the summer training into their classrooms and gained a deeper understanding of science.

Blanchard, Southerland, & Granger (2009) studied the effectiveness of a professional development program in which teachers participated in the Marine Ecology for Teachers Program. The program was deliberately constructed in a way that facilitated teachers' comprehension of inquiry as a method for research and a science teaching strategy. A six-week program at a biological field station engaged four teachers in genuine hypothesis generation, experimentation, and data collection regarding snail behavior. Teachers presented their research to the entire group after the researchers collected the data.

In addition to the research in which the teachers engaged, they also participated in a course on inquiry-based instruction taught by two master teachers. Through this process teachers were required to reflect on the experiences they had in the field, and make connections to the inquiry process and pedagogical features of inquiry-based instruction that had been modeled throughout their field experience. The culminating activity for this program was that the teachers adapted a lesson from the content areas they taught to an inquiry-based format (Blanchard, et al., 2009).

The teachers in the Blanchard, et al. (2009) study were tracked following the summer program. The researchers found teachers who began the program with a more refined, theory-based understanding of inquiry were better able to understand the inquiry-based teaching methodology and use it in their classrooms. Further, the authors suggested inquiry-based PD was potentially more effective for teachers if they were primed because as noted, the teachers who were the most successful in this program already had ideas about inquiry-based learning.

Jeanpierre, Oberhauser, & Freeman (2005) conducted a study to identify characteristics of PD experiences that would be helpful in preparing teachers to integrate inquiry-based teaching methods into their classrooms. To explore this phenomenon, researchers sent 44 teachers of various experience levels on two weeklong PD trips where they studied monarch butterfly ecology. The first workshop took place in Minnesota, during the breeding time for monarchs, and the second was in Texas, during the monarchs' migration. During each of the workshops, scientific researchers assisted teachers in designing and conducting their own inquiry-based research projects. Teachers spent nearly ten hours per day on activities for the project, and in addition to scientific fieldwork, most days included presentations on ecology topics or the processes of scientific inquiry. Additionally, teachers were regularly engaged in activities that presented ideas for how to integrate inquiry-based processes into classroom settings (Jeanpierre et al., 2005).

Findings from the Jeanpierre et al. (2005) study suggested the program was successful in preparing teachers to integrate inquiry into their classrooms. Of teachers who were not using any inquiry in their classrooms prior to the workshops, 57% moved into the almost-doing or doing categories. Of teachers who were already almost using inquiry in their classrooms prior to the workshops, 100% were using inquiry after. The aspects of this program that seemed to be the most beneficial to the teachers were an improvement in science content and inquiry-oriented process knowledge and plentiful opportunities for practice.

As a part of the Arizona Collaborative for Excellence in the Preparation of Teachers (ACEPT) Program, a reform effort supported by the National Science Foundation, Adamson et al. (2003) studied the effect of enrollment in a reformed teaching methods undergraduate course on pedagogy and student achievement. Reformed teaching methods are based on the principles of effective teaching introduced by the American Association for the Advancement of Science (1989). Among other values, these principles state that teaching should be consistent with the nature of scientific inquiry and should reflect scientific values (American Association for the Advancement of Science, 1989; Adamson et al., 2003). The typical ACEPT program involves month-long summer workshops where college faculty learn about reformed teaching and then apply it in their classes (Adamson et al., 2003). The summer workshops mirror many other successful inquiry-based professional development programs by introducing participants to inquiry by first modeling inquiry-based methods and allowing teachers to experience them first hand, as students. The ACEPT workshops then challenge teacher participants to develop inquiry-based lessons for immediate use in their courses. Upon evaluation, these summer workshops appear to have boosted undergraduate student achievement (Adamson et al., 2003). Additionally, in terms of the biology teachers and students studied, the teachers who took a reformed methods course as undergraduates demonstrated stronger pedagogical skills in terms of inquiry compared to teachers who did not participate in an inquiry-based methods course (Adamson et al., 2003).

Each of these studies highlight the importance of integrating authentic inquiry-based experiences in PD intended to teach about the power of inquiry-based teaching methods. As Kurt Lewin, as cited in Kolb (2014), suggested, providing learners with an immediate personal experience served as an extremely effective foundation for learning; through these types of experiences teachers were able to find personal meaning in the often-abstract concept of scientific inquiry (Kolb, 2014). Consequently, the use of inquiry-based PD is a key aspect included in my study.

Adult Learning Theory

When structuring learning or professional development experiences, considering how adults learn is crucial for success and sustainability of change. According to Speck (1996), adults want to be the origin of their own learning and will resist learning activities they perceive as an attack on their competence. Consequently, giving participants some control of the design of their learning experiences may support participation in learning experiences and generate a sense of ownership (Speck, 1996; Datnow & Castellano, 2000). Speck (1996) also maintains that adult learners need direct, concrete experiences where they can apply what they learn to their work. Additionally, if professional development experiences are structured in a manner that provides support from peers, opportunities for feedback and practice, and a chance to reflect, share, and generalize their learning, participants will be far more likely to transfer the learning into practice

(Speck, 1996). To achieve this type of professional development, the experience must be more than a one-shot treatment. Follow-up support and coaching are necessary to help adult learners transfer new ideas into practice in a way that is sustainable (Speck, 1996).

Another aspect to consider when designing professional development experiences is the body of experience that adult learners bring with them to learning activities. Throughout life we acquire unique associations, concepts, values, feelings, and conditioned responses that shape the way we view the world. These structures of assumptions through which we understand our experiences are often referred to as frames of reference (Davis, 2006; Mezirow, 1998; Taylor, 2008). In terms of new learning experiences, we have a strong tendency to reject ideas that fail to fit our preconceptions (Davis, 2006; Mezirow, 1998; Taylor, 2008). When we experience a challenge to a belief, on a subconscious level we feel as though it is a challenge to our identity, and our brains prepare for an attack on self-esteem (Westen, Blagov, Harenski, Kilts, & Hamann, S., 2014; Nyhan & Reifler, 2016; Graves, 2016). When Westen et al. (2014) examined what occurs in the brain when we are challenged with evidence that suggests we may be incorrect, they discovered increased activity in areas of the brain related to emotion, conflict, moral judgments, and reward, but low activity in the area of the brain responsible for rational reasoning (Westen et al., 2014; Graves, 2016). In order to help individuals be more willing to acknowledge uncomfortable facts that conflict with their perceptions, researchers suggest that affirming individuals' self-worth may be an effective strategy (Nyhan & Reifler, 2016; Graves, 2016). Nyhan and Reifler (2016) also found that affirmation could help reduce misperceptions if no other information could be provided.

The findings by Westen et al. (2014) and Nyhan and Reifler (2016) are consistent with the concepts of transformative learning. Transformative learning involves disrupting prior understandings and reshaping deeply ingrained assumptions and belief structures (Davis, 2006; Mezirow, 1998; Taylor, 2008). According to transformative learning, stimulating new, progressive thinking on individual and group levels can be achieved through critical self-reflections and participating in discourse (Davis, 2006; Mezirow, 1998; Taylor, 2008).

Together, this information about how adults learn, how our brains respond to information that challenges deeply rooted beliefs, and how to stimulate new thinking that can reshape existing conceptions is extremely helpful in designing learning experiences and professional development. Allowing participants to act as co-constructors of the experience, providing concrete, first-hand experiences that can be immediately applied, and relaxing participants through affirmation, discourse, and opportunities for reflection may ultimately make the professional development experience considerably more successful and sustainable (Speck, 1996; Datnow & Castellano, 2000; Davis, 2006; Mezirow, 1998; Taylor; Westen et al., 2014; Nyhan & Reifler, 2016; Graves, 2016).

Fidelity of Implementation and Co-construction

Every aspect of our lives is socially constructed. What individuals perceive as reality is a product of their particular culture and experiences (Gergen, 2009). This acquired body of experience includes our associations, concepts, values, feelings, and conditioned responses and shapes our frames of reference (Davis, 2006; Mezirow, 1997, 1998; Taylor, 2008). Frames of reference are constructions of assumptions through which we understand our experiences that define our world (Davis, 2006; Mezirow, 1997, 1998;

Taylor, 2008). Individuals tend to reject ideas that fail to fit with preconceived notions (Davis, 2006; Mezirow, 1997, 1998; Taylor, 2008). Overcoming these tendencies requires gaining knowledge that disrupts preconceptions and encourages the restructuring of deeply held assumptions and belief structures (Davis, 2006; Mezirow,1997, 1998; Taylor, 2008). This process involves self-reflection and participating in dialogue to renegotiate beliefs, intentions, values, and feelings (Davis, 2006; Mezirow, 1997, 1998; Taylor, 2008). With this process in mind, and in order to make the work with my department authentic and effective, I approached the design of my study through the lens of a constructivist paradigm of knowledge acquisition.

Given the locally generated construction of my innovation, I found it more appropriate to view the change process as a co-construction rather than an imposition from the top down. Through the process of designing the innovation alongside the biology teachers in my department, I intended to allow it to be as much of an organic, bottom-up process as possible. That being said, I was not interested in measuring the fidelity of implementation according to a technical-rational, objectified standard. I believed that variation in implementation among the participating biology teachers was inevitable, as they each bring their own unique set of experiences and perspectives to their teaching.

Berman and McLaughlin (1978) coined the phrase “mutual adaptation” to describe the mutually adaptive process between the individual and the institutional setting (Datnow, Hubbard, & Mehan, 2002). As Berman and McLaughlin (1978) imply, not only is mutual adaptation inevitable, it is desirable (Datnow, Hubbard, & Mehan, 2002). The freedom to negotiate and adjust an innovation to fit the frames of reference of particular teachers is key to successful, sustainable reform (Snyder, Bolin and Zumwalt 1992; Datnow, Hubbard, & Mehan, 2002). Although I still modeled what I believed was best practice in terms of inquiry-based pedagogy, I believed it is inevitable that teachers would modify what we covered throughout the semester to fit with what was required to meet the practical demands of their everyday teaching lives (Datnow, Hubbard, & Mehan, 2002).

Conclusion

Extant research suggested to me that carefully crafting first hand experiences was essential for learning throughout life. In terms of science PD, research indicated that to successfully teach science through an inquiry-based approach, teachers needed to have familiarity and training with scientific inquiry themselves (Capps et al., 2012; NRC, 1996; Westerlund, Garcia, Koke, & Mason, 2002). Consequently, researchers recommended having teachers participate in genuine scientific research during professional development (Capps et al., 2012; NRC, 1996; Westerlund et al., 2002).

Establishing new ways of thinking about how the world works requires relearning and the resolution of conflicts between longstanding notions and exposure to new concepts and approaches. In order to address these conflicts in a PD program, research suggests allowing participants to act as co-constructors of the experience (Speck, 1996; Datnow & Castellano, 2000; Davis, 2006; Mezirow, 1998; Taylor, 2008; Westen et al., 2014; Nyhan & Reifler, 2016; Graves, 2016). A co-constructed approach can provide concrete, first-hand experiences that can be immediately applied, and eases participants through the learning process with affirmation, discourse, and opportunities for reflection (Speck, 1996; Datnow & Castellano, 2000; Davis, 2006; Mezirow, 1998; Taylor, 2008;

Westen et al., 2014; Nyhan & Reifler, 2016; Graves, 2016). I expected this co-constructed methodology to maximize the success and sustainability of the PD experience (Speck, 1996; Datnow & Castellano, 2000; Davis, 2006; Mezirow, 1998; Taylor, 2008; Westen et al., 2014; Nyhan & Reifler, 2016; Graves, 2016).

As described in the first chapter, many students are currently leaving high school without critical reasoning skills (Perie, Grigg, & Donahue, 2005). At the large, comprehensive, suburban high school where I teach and serve as the science department chair many students are also leaving high school without experiencing scientific inquiry in a way that contributed to their ability to think critically. This problem is due in part to the lack of laboratory activities that allowed time for students to engage in creative thinking, problem solving, and reasoning. In order to address these issues, I conducted an innovation that allowed me to work with the teachers in my department to co-construct an inquiry-based professional development experience and long-term plan to support teaching via scientific inquiry. The focus of this study was to investigate the extent to which an inquiry-based professional development experience[1], including a two-day summer workshop as well as 18 weeks of follow up PLC support, affected the attitudes and pedagogical skills regarding scientific inquiry among six high school biology teachers.

[1] Throughout the remainder of the paper, references to the "inquiry-based professional development experience" refer to the two-day summer workshop and subsequent 18 weeks of PLC follow up employed in this study.

The following research questions describe what I desired to learn from my study:

1. How and to what extent does an inquiry-based professional development experience influence six high school biology teachers' attitudes and perceptions regarding inquiry-based pedagogy?
2. How does an inquiry-based professional development experience affect how well six high school biology teachers implement an inquiry-based pedagogy?

CHAPTER 3

METHOD

Introduction

In the years leading up to this study, many students across the country were leaving high school without critical reasoning skills (Perie, Grigg, & Donahue, 2005). At the large, comprehensive, suburban high school where I teach and serve as the science department chair, many students were also failing to develop critical reasoning skills. This problem was due in part to students leaving high school without experiencing scientific inquiry in a way that contributed to their ability to engage in creative thinking, problem solving, and reasoning. In order to address these issues, I worked with the teachers in my department to create a professional development experience and long-term plan to support teaching via scientific inquiry. The following is a description of the method I employed to investigate the extent to which a co-constructed inquiry-based professional development experience affected the attitudes and pedagogical skills regarding scientific inquiry among six high school biology teachers.

Research Methodology

A concurrent mixed methods, action research design was used to gather data. Action research is conducted by practitioners and allows for information gathering in their own setting (Mertler, 2014). Using action research allowed me to better understand my school and test ways to improve its effectiveness from the inside (Mertler, 2014). Quantitative measures were first used to establish a baseline measure of teacher skills, efficacy, and attitude regarding inquiry in the form of a survey and card sorting task designed to elicit teachers' knowledge and beliefs about the purposes and goals for teaching science (Friedrichsen & Dana, 2003). Gathering quantitative data first provided me with a more informed lens during the subsequent qualitative measures. Following the summer workshop, which is described, below, effectiveness of the workshop activities and teachers' subsequent implementation of inquiry-based pedagogy was assessed through qualitative and quantitative instruments. Quantitative data was obtained through surveys and the Reformed Teaching Observation Protocol (RTOP) (Piburn & Sawada, 2000). Research suggests the RTOP accurately predicts improved student learning in science classrooms at all levels and assesses a single construct of inquiry (Piburn & Sawada, 2000). Qualitative data was gathered through individual interviews, PLC meeting observations, and interviews. Together the quantitative and qualitative measures were used to better understand how teachers experience the transition to an inquiry-based pedagogy.

Site

The study took place within the science department of a large, comprehensive, suburban high school where I teach and serve as the science department chair. The school is located in a large metropolitan area of Arizona with a current enrollment of approximately 2,900 students. Families in the neighborhood the school serves are primarily middle-class or upper-middle-class, with only 5% of the student population qualifying for free lunch. 63% of the student population is Caucasian, 16% is Hispanic, 9% is Asian, and 6% is African-American (USNWR, 2015). This school consistently received "A" grades from the Arizona Department of Education, indicating high levels of academic achievement, and had 107 AP Scholar Awards and over 100 National Merit Scholarship finalists last year (TUHSD, 2015).

The science department has consistently offered a variety of unique laboratory science courses and maintained a reputation for success. Nevertheless, in the years leading up to the study, there was a decline in the frequency of the science teachers doing inquiry-based laboratory activities that allow time for students to experience genuine curiosity, creative thinking, problem solving, and the use of critical reasoning skills.

I was selected to serve as the science department chair in the spring of 2015, and have made encouraging the use of inquiry-based teaching methodologies the cornerstone of my role. From the time I began working at my school in 2012 until the summer of 2016, district personnel increasingly placed pressure on teachers to cover specific standards by certain points in the semester. During these years, progress was measured through the collection of district-wide, content-based quarterly assessment data. As these assessments were developed and rolled out, many teachers felt they did not have enough time to cover all of the material required and still spend valuable class time engaging in authentic experimentation and inquiry. As a result, inquiry-based teaching was gradually phased out of science classrooms in favor of direct instruction. In an attempt to revive the exploratory nature of our science classes and promote the development of critical reasoning skills among students, in my role as a department chair, I persuaded district personnel to reconstruct these quarterly assessments to assess a wider range of skills, including scientific reasoning abilities, rather than focusing exclusively on content knowledge. Unfortunately, even though these revised assessments assess a wider range of skills, they still do not precisely assess student reasoning skills and require cumbersome data entry for each student, which takes away valuable time teachers could be spending planning high-quality lessons for their students. Additionally, the persistence of the

AIMS Science test, which primarily assesses content-knowledge as a statewide means of measuring student achievement in science, and the emphasis on content knowledge by district and local administrators is still fresh in the minds of teachers. This environment makes transitioning teachers to an inquiry-based approach to science teaching a challenging task.

Despite this conflicted environment, I worked with the biology teachers in my department in the years leading up to the study to encourage them to transform their instruction from a relatively didactic approach to one that was inquiry-based. As described in my literature review, research suggests that when teachers have some prior knowledge before inquiry-based professional development the likelihood of success is improved. For example, among teachers who were close to using inquiry in their classrooms prior to summer workshops, 100% were using inquiry after (Jeanpierre et al., 2005). In the present study, I built on this foundation of prior knowledge on inquiry-based instruction that I had previously been building with my teachers and employed an inquiry-based approach to professional development to assist the biology teachers in my department in reconstructing their curriculum to an inquiry-based format.

Participants and Sampling

I used purposive sampling (Given, 2008) to deliberately select six teacher participants for this study who teach biology and participate in a weekly biology Professional Learning Community (PLC). The six teacher participants included two males and four females ranging in teaching experience from five years to twenty-five years. These teachers also varied in their level of experience with inquiry-based pedagogy and provided instruction for courses with a diverse population of students, from students with Individual Education Plans (IEPs) to honors students. This dynamic learning environment was useful in demonstrating how inquiry-based laboratory activities could be tailored to fit the needs of students of all levels.

Role of the Researcher/Practitioner

As the science department chair and a teacher at the school where the study took place, I acted as the primary content creator, researcher, and practitioner. My principal responsibility as the primary coordinator and creator of the content of the professional development workshops was to craft a meaningful program in which teachers had the opportunity to experience inquiry-based learning first hand and discuss and create strategies together for implementing scientific inquiry in their classrooms. My role as researcher was to collect both qualitative and quantitative data and analyze it. This process included conducting observations, administering pre- and post- intervention survey instruments, conducting pre- and post- intervention interviews, and collecting field notes. As a practitioner, I offered support, help, encouragement, and resources to the participating teachers throughout the innovation process as a fellow teacher.

Procedures

To increase teachers' knowledge of scientific inquiry and help them learn how to more effectively implement an inquiry-based instructional method in their classrooms I constructed a plan to deliver a professional development experience through an immersive two-day summer workshop followed by 18 weeks of follow up support during PLCs to facilitate continued learning and implementation.

The summer workshop. To begin my study, I created a two-day inquiry-based professional development experience for teachers. Although the literature suggested a week-long workshop with follow up support as most effective, due to time constraints of the teachers and their experience level, a two-day workshop was sufficient (Jeanpierre et al., 2005; Kolb, 2014; Blanchard, et al., 2009; Radford, 1998; Westerlund et al., 2002). The summer professional development served as an opportunity for teachers to experience inquiry first-hand, and to participate in activities, discussions, and reflections to build knowledge about how students think, and how and why inquiry-based teaching is so effective at developing higher level reasoning skills. During the summer workshop teachers also developed a plan to reconstruct their curriculum to an inquiry-based format and mapped out what they wanted to achieve in the following semester. A detailed outline of the workshop is provided in Table 1, below.

Table 1.

Workshop Outline

Day	Activities	Outcomes
Day 1	Card Sorting Activity	Established baseline levels of teachers' knowledge and beliefs about science teaching
	Model inquiry-based lesson taught by local physics teacher.	Teachers experienced inquiry first-hand and identified incongruences between the model inquiry-based lesson and the way they currently use inquiry in their classroom.
	Teachers worked through the first three of six modules with activities, discussions, and reflections.	Teachers participated in activities, discussions, and reflections to establish ideas about how students think, concrete and formal reasoning patterns, and the learning cycle.
	Applied principles of inquiry-based teaching to convert a traditional lab teachers currently use to one that is inquiry-based.	Teachers identified weak aspects of a traditional lab and worked through the process of converting it to an inquiry-based format.
Day 2	Teachers worked through the remaining three of six modules with activities, discussions, and reflections.	Teachers participated in activities, discussions, and reflections to establish ideas about concrete and formal concepts, tests and self-regulation, and provided time for planning and goals.
	Discussed how to best use PLC time in the fall semester to support using inquiry-based teaching methods.	Teachers constructed a plan for the fall semester to support their efforts in using inquiry in their classrooms.

PLC support. After the summer professional development workshop described above, the weekly PLC meetings during the following fall semester provided a space to offer support, receive structured, helpful feedback, and reflect on their experiences with inquiry-based teaching. After my initial cycle of inquiry in the spring of 2016 I handed over control of the biology PLC to a teacher I worked with who demonstrated exceptional potential. This allowed me to remove the focus from myself and more organically allow the enthusiasm surrounding the transition to inquiry to grow. Assuming a more supportive role also allowed me to help steer the conversation and afforded me the opportunity to observe and collect field notes. All of the six participating teachers and myself were present at all PLC meetings, with the exception of one teacher who had a baby and went on maternity leave midway through the semester. This teacher who left midway through the semester was also the teacher leader who took over the control of the biology PLC. When she was absent in the middle of the semester, another teacher from the group stepped in to facilitate our meetings. Throughout each PLC meeting I participated, observed, and took field notes. I first allowed teachers to provide help to one another and if there was something additional I could offer in terms of support or advice, I submitted that to the group as well. Through the weekly PLC meetings, I hoped to create a culture of collaboration and support among the biology teachers so that they felt comfortable sharing resources and building materials that would help students develop critical reasoning skills.

Instruments

Teacher surveys. Prior to the summer workshop and at the end of the entire PD experience, including the 18 weeks of PLC follow up, teachers completed a survey instrument comprised of researcher-developed questions as well as questions from the Report of the 2012 National Survey of Science Education (Banilower, Smith, Weiss, Malzahn, Campbell, & Weis, 2013, p. 22). The survey instrument gathered information regarding research question (RQ) 1: How and to what extent does an inquiry-based professional development experience influence six high school biology teachers' attitudes and perceptions regarding inquiry-based pedagogy? The survey assessed three constructs: *perception of skill using inquiry-based teaching, perception of efficacy regarding inquiry-based teaching, and attitude toward using inquiry-based teaching.* Each of constructs on the survey contained five items. Sample survey items to demonstrate the nature of what the items looked like for each of the constructs are as follows: *perception of skills with inquiry-based teaching* – "I can use inquiry-based teaching methods in my own classroom"; *perception of efficacy regarding inquiry-based teaching* – "I feel that I could easily implement inquiry-based teaching in my own classroom"; and *attitude toward inquiry-based teaching* – "It is better for science instruction to focus on ideas in depth, even if that means covering fewer topics." All items were assessed with a 6-point Likert scale ranging from 6 = *Strongly Agree* to 1 = *Strongly Disagree*. The entire survey is provided in Appendix A.

Card sorting task to elicit science teaching orientations. A card sorting activity adapted from a procedure developed by Friedrichsen & Dana (2003) was used to assess teachers' knowledge and attitudes about the purposes and goals for teaching science. The card sorting activity served as an instrument to gain more information regarding aspects of RQ1: How and to what extent does an inquiry-based professional development experience influence six high school biology teachers' attitudes and perceptions regarding inquiry-based pedagogy?

I began the summer workshop with this card sorting activity and asked teachers to repeat the activity at the end of the entire PD experience. Both times the card sorting activity was completed by the teachers, I asked the teachers to read the set of scenario cards and place each card into one of two stacks: this scenario represents how I would teach, this scenario does not represent how I would teach. Upon completion I had teachers label the stacks with pre-constructed labels and then secure them with rubber bands. Friedrichsen & Dana (2003) included three stacks in their original activity, but I chose to eliminate the third option: unsure, and force teachers to choose a side.

To demonstrate the nature of what these questions looked like, I have included a description provided on one of the sample scenario cards. One item to assess teachers' attitudes about the purpose of science education was, "You, as a teacher, have your students first engage in laboratory activities, then follow-up with class discussion." A full list of the scenario cards is provided in Appendix B. At the beginning of the summer workshop, after the cards were sorted, I asked the group whether any scenarios evoked a strong positive or negative reaction, and discussed those together.

After repeating the card sorting activity after the final PLC meeting of the fall semester, I analyzed the teachers' responses to see how they changed from the beginning to the end of the professional development experience. Friedrichsen & Dana (2003) did not design the task in a way that was meant to provide a score for the participants; however, for the purposes of the current study, I thought it would interesting to analyze the items teachers chose in terms of comparing pre- post- choices, as well as comparing this data to data from RTOP observations, surveys, and interviews. To do this, I classified each item in the card sorting task as being either student-centered, activity-centered, or teacher-centered. The activity-centered options could be potentially used in an inquiry-based manner, but the way they are described in the task are not representative of wholly student-centered activities and would not require the use of critical reasoning skills by students. Including these three categories in the task was helpful in gaining a more accurate representation of teachers' attitudes and perceptions about inquiry-based pedagogy than the survey alone. Because of the way the survey items were phrased, in a relatively transparent method where teachers could likely decipher the intent, I suspected teachers might simply tell me what they thought I wanted to hear, or overestimate their abilities, as I am technically their direct supervisor. I thought the card sorting activity would provide a more accurate picture, because it is harder to decipher which items represent student-centered activities, activity-centered activities, or teacher-centered activities. By asking teachers to classify activities as either something they would or would not do as a teacher, I was able to better inform my understanding of their attitudes and perceptions of inquiry.

Classroom observations using the Reformed Teaching Observation Protocol. I observed each teacher three times throughout the course of the study: once at the beginning of the semester, shortly following the summer workshop; once in the middle of the semester; and once at the end of the semester. The observations served as a means to gain more information regarding aspects of RQ 2: How does an inquiry-based professional development experience affect how well six high school biology teachers implement an inquiry-based pedagogy?

During the observation visits I used the Reformed Teaching Observation Protocol

(RTOP) to score the teachers (Piburn & Sawada, 2000). Research suggests the RTOP accurately predicts improved student learning in science classrooms at all levels and assesses a single construct of inquiry (Piburn & Sawada, 2000). The RTOP consists of 25 items split into five sub-constructs, each containing five items: *lesson design and implementation*, *propositional knowledge*, *procedural knowledge*, *community interactions*, and *student/teacher relationships*. To demonstrate the nature of what aspects were assessed in each construct, sample items for each of the constructs are provided. One item to assess *lesson design and implementation* was, "The focus and direction of the lesson was often determined by ideas originating with students." One item to assess *propositional knowledge* was, "The lesson promoted strongly coherent conceptual understanding." One item to assess *procedural knowledge* was, "Students were actively engaged in thought-provoking activity that often involved the critical assessment of procedures." One item to assess *communicative interactions* was, "Students were involved in the communication of their ideas to others using a variety of means and media." One item to assess *student/teacher relationships* was, "Students were encouraged to generate conjectures, alternative solution strategies, and ways of interpreting evidence." The entire RTOP instrument is provided in Appendix C.

I used RTOP to help track skill development throughout the professional development experience, and used survey and interview data to help make sense of the findings. A copy of the RTOP is provided in Appendix C.

Individual teacher interviews. In addition to collecting survey and observation data, semi-structured interviews were conducted at the end of the professional development experience at the end of the semester. The interviews served as instruments to gain more information regarding aspects of RQ 1: How and to what extent does an inquiry-based professional development experience influence six high school biology teachers' attitudes and perceptions regarding inquiry-based pedagogy? and RQ 2: How does an inquiry-based professional development experience affect how well six high school biology teachers implement an inquiry-based pedagogy?

The questions for the interviews were designed to gain more information about teachers' attitudes and perceptions regarding inquiry-based pedagogy, and the usefulness of structuring the PD experience the way I did, informed by ideas from transformative learning (Davis, 2006; Mezirow, 1998; Taylor, 2008), adult learning theory in PD (Speck, 1996), and mutual adaptation (Berman & McLaughlin, 1978, Snyder; Bolin and Zumwalt 1992; Datnow, Hubbard, & Mehan, 2002). A full description of the interview questions is provided in Appendix D.

PLC Observations. Throughout the fall semester I observed the biology PLC meetings each week. These observations served as a means to gain more information regarding aspects of RQ 1: How and to what extent does an inquiry-based professional development experience influence six high school biology teachers' attitudes and perceptions regarding inquiry-based pedagogy?

During these observations I kept field notes and paid special attention to communication regarding experiences with inquiry-based activities. The PLC meetings were a place where teachers collaboratively worked on ideas for lessons and labs, and discussed and reflected on their experiences. Observing these meetings helped me gain information about how teachers were experiencing the innovation and the transition to an inquiry-based approach.

An instrument inventory is provided in Table 2.

Table 2

Data collection instruments and justifications

Data collection instrument	Justification	Research Questions Addressed
Teacher Surveys	Helped gain an understanding of how teachers changed over the course of the study in terms of their perception of skills, efficacy, and attitudes regarding inquiry-based pedagogy	1
Card Sorting Activity	Helped gain an understanding of teachers' knowledge and attitudes about the purposes and goals for teaching science	1
Classroom Observations Using RTOP	Three observations using RTOP throughout the study allowed me to track changes in the teachers' lesson design and implementation, propositional knowledge, procedural knowledge, communicative interactions, and student/teacher relationships throughout the professional development experience	2
Individual Interviews	Individual semi-structured interviews with teachers helped me gain a better understanding of how teachers experience the transition to an inquiry-based pedagogy	1, 2
PLC Observations	Observing weekly biology PLC meetings and keeping field notes helped me gain a better understanding of how teachers were experiencing the transition to an inquiry-based pedagogy	1

Data Collection Procedures and Analysis

Teacher surveys. In order to collect data before the summer workshop and after the entire PD experience, including the 18 weeks of follow up PLC support, and assess the teacher participants' perception of skills using inquiry-based teaching, perception of efficacy regarding inquiry-based teaching, and attitude toward using inquiry-based teaching, a survey instrument was administered. The full survey instrument is attached in Appendix A. Prior to the administering the survey, consent was obtained through the IRB approved recruitment-consent form, which is attached in Appendix F.

All participating teachers completed the survey electronically prior to the summer workshop and at the end of the semester, after the workshop and all subsequent PLC meetings. The surveys were initially scored in Google Forms and then a descriptive analysis was conducted using SPSS 24 © software. The questions were grouped into three categories: perception of skills using inquiry-based teaching, perception of efficacy regarding inquiry-based teaching, and attitude toward using inquiry-based teaching. In SPSS 24 ©, I created a new pre- and post- variable for each construct to reflect a score for each of the three constructs before and after the PD experience. In the third construct of the survey, four of the five responses were in the opposite orientation as the rest of the items in the survey; rather than (1) being a score that was negatively associated with inquiry, and (6) being a score that was positively associated with inquiry, they were the opposite. To adjust for this difference, I manually flipped the scores for each participant for these items so the scale would match the other questions. These final scores for each construct were the mean of all items associated with the construct. Additionally, the mean and standard deviation for each construct was calculated for each participant. I then used SPSS 24 © to conduct a paired-samples *t*-test to compare the mean scores from pre- and post- to establish whether the differences were statistically significant.

Card sorting task to elicit science teaching orientations. At the beginning of the summer workshop and during the final PLC meeting of the fall semester I used the card sorting activity to assess teachers' knowledge and attitudes about the purposes and goals for teaching science. Upon completion, I analyzed the teachers' responses and compared the data from the two sessions to see how the teachers' knowledge and attitudes changed from the beginning to the end of the professional development experience. The data from the card sorting task was scored by hand and analyzed using SPSS 24 © software. I constructed three variables to represent each category of items included in the card sorting task: student-centered items, activity-centered items, and teacher-centered items. I analyzed the mean and standard deviation of each category in both the pre- and post- assessments. I then used SPSS 24 © to conduct a paired-samples *t*-test to establish whether the differences between the mean scores from the pre- and post- for each category were statistically significant.

Classroom observations using the Reformed Teaching Observation Protocol. Fifty-minute classroom observations were conducted for each of the participating teachers three times throughout the fall semester. During the observations of these teachers' classrooms, the RTOP was used to score the teachers' ability to effectively use inquiry as a means of instruction. The RTOP observation data was scored by hand and analyzed using SPSS 24 © software. I constructed variables for each RTOP construct and for the total score of each of the observations. I analyzed the mean and standard deviation of each of the constructs and total score for each observation. I then constructed six charts, one for each of the five sub-constructs and a sixth to illustrate the total aggregate sub-constructs. On each chart I included trend lines for each sub-construct for each teacher individually, plus a line showing the aggregate average. Using charts to depict the RTOP data was useful for seeing the actual growth trajectory for each teacher over the three time periods.

Individual teacher interviews. Semi-structured interviews were conducted after the entire PD experience with each teacher. The interviews were ten to twenty-minutes long and the questions were introduced in the order that they are described in Appendix D. Follow up questions were posed when they were appropriate. The interviews were recorded with iPhone software for convenience and transcribed upon completion. Prior to the interviews, consent was obtained through the IRB approved recruitment-consent form, which is attached in Appendix F. Each interview took place in the office of the teacher being interviewed.

The qualitative data was coded using hypothesis codes that allowed me to apply theory-driven codes of what might arise in the data before analysis was performed (DeCuir-Gunby, Marshall, & McCulloch, 2011; Saldana, 2009), along with data-driven codes I developed from additional themes that arose from my field notes. The theory-driven predetermined hypothesis codes were informed by my research questions as well as my broader literature review. Although constructing pre-determined codes may have focused the parameters of the analysis somewhat narrowly, hypothesis coding was an efficient way for me to approach the interview data (Saldana, 2009). I conducted the interviews in the final week of the study, after 21 weeks of working with the participants. After working with the participants for so long I was able to confidently go into the interview analysis with some idea of what was most likely happening.

Using this hypothesis coding approach, I reviewed my research questions and broader literature review and came up with 18 codes informed by concepts from transformative learning (Davis, 2006; Mezirow, 1998; Taylor, 2008), adult learning theory in PD (Speck, 1996), mutual adaptation (Berman & McLaughlin, 1978, Snyder;

Bolin and Zumwalt 1992; Datnow, Hubbard, & Mehan, 2002), and over-arching themes of teaching pedagogy consistent with the nature of scientific inquiry (AAAS, 1989, NRC, 1996, Piburn & Sawada, 2000). I grouped these codes into two larger categories, dealing with *teachers' attitudes and perceptions* regarding inquiry-based pedagogy, and the *structure of the PD experience*.

I also created four additional data-driven codes based on my field notes and observations during PLC discussions throughout the semester to address commonly cited *challenges* for teachers in terms of implementing inquiry-based teaching methods in their classrooms. The three categories and their respective codes are described in Table 3, below. I also included a column in the table to address what was informing the creation of each particular hypothesis code.

Table 3

Hypothesis Codes, Categories, and Origins

Category	Codes	Origin
Teachers' attitudes and perceptions of inquiry-based pedagogy	Start with questions about nature	(NRC, 1996, pg. 30, Piburn & Sawada, 2000)
	Engage students actively	(NRC, 1996, pg. 30, Piburn & Sawada, 2000)
	Collection and use of evidence	(NRC, 1996, pg. 30, Piburn & Sawada, 2000)
	What students learn is influenced by their existing ideas	(AAAS, 1989, pg. 145, Piburn & Sawada, 2000)
	Meet the interests, knowledge, understanding, abilities, and experience of the students	(NRC, 1996, pg. 30, Piburn & Sawada, 2000)
	Encourage and model the skills of scientific inquiry as well as	(NRC, 1996, p. 32, Piburn & Sawada, 2000)

	the curiosity, openness to new ideas	
	Teachers and students collaborate in the pursuit of ideas, and students often initiate new activities	(NRC, 1996, pg. 33, Piburn & Sawada, 2000)
	Community of science learners	(NRC, 1996, pg. 31, Piburn & Sawada, 2000)
	Students explain and justify their work to themselves and one another	(NRC, 1996, pg. 33, Piburn & Sawada, 2000)
Structure of the PD experience	Freedom to negotiate and adjust innovation through mutual adaptation	(Berman & McLaughlin, 1978, Snyder; Bolin and Zumwalt 1992; Datnow, Hubbard, & Mehan, 2002)
	Teachers having some prior knowledge of inquiry before the PD experience (Reinforcement and support for inquiry)	(Jeanpierre et al., 2005)
	Support from peers	(Speck, 1996)
	Opportunities for feedback and practice	(Speck, 1996)
	Chance to reflect, share and generalize learning	(Speck, 1996)
	Follow-up support and coaching	(Speck, 1996)
	Reshaping deeply ingrained assumptions and belief structures	(Davis, 2006; Mezirow, 1998; Taylor, 2008)
	Critical self-reflections	(Davis, 2006; Mezirow, 1998; Taylor, 2008)
	Participating in discourse	(Davis, 2006; Mezirow, 1998; Taylor, 2008)
Challenges	Issues steering labs/getting imperfect results/giving up control	Field notes

	Difficulty with lower-level/un-invested students
	Large class sizes
	Conflicting initiatives from district office administrators

Once I had established these three categories and 22 codes, I coded each interview in Microsoft Word by hand. In order to make sense of patterns among the interviews of the participants, I created a table to compare the frequencies of teachers mentioning particular codes. After analyzing the data in this way, total frequencies were added to provide a broader view of the data as a whole. The codes and their frequencies in the interviews are provided in Appendix E. The interview data was also triangulated with data from RTOP observations and card-sorting and survey data, which allowed me to discover interesting patterns and themes within the data.

PLC Observations. During the PLC observations, I collected data through the use of field notes. The field notes and memos that I constructed from the PLC observations were analyzed for patterns and recorded. General themes were established, which led to the development of assertions that could be compared to data collected during interviews, individual classroom observations using RTOP, and survey data.

Study Timeline

The overall timeline for my study is described in Table 4, below.

Table 4

Timeline and Procedures

Time Frame	Actions	Procedures
March – December 2017	Researcher journal	Kept a researcher jounal throughout to describe the experience
April 2017	Recruited teachers for workshop	Determined whether teachers were willing and interested Distributed recruitment-consent forms and obtained signatures
July 2017	Administered pre-workshop survey	Administered survey
July 2017	Administered pre-workshop card sorting activity	Administered card sorting activity
July 2017	Conducted workshop	Conducted 2-day summer workshop with six biology teachers
August 2017 - December 2017	Support weekly PLC meetings	Provided opportunities for reflections, collaboration, and resources
August 2017 - December 2017	Teacher observations	Observed teachers three times each using RTOP to assess progress using inquiry-based teaching pedagogy
December 2017	Administered pre-workshop survey	Administered survey
December 2017	Administered pre-workshop card sorting activity	Administered card sorting activity
December 2017	Administered teacher interviews	Interviewed each participating teacher
December 2017	Analyzed and evaluated data	Transcribed audio recordings from interviews Conducted qualitative analysis of interviews and quantitative analysis of card-sorting data, survey data, and RTOP data

Threats to Validity

Experimenter Effect. My positionality as department chair may have influenced how the participating teachers responded to the survey and card sorting items, and to the interview questions. In order to minimize this effect, I actively worked to develop a positive, sociable relationship with each teacher in the participant group. I also assumed a participatory role in the research and allowed for co-construction and mutual adaptation of the innovation. As discussed in Chapter 2, research suggested the freedom to negotiate and adapt an innovation to particular frames of reference supports successful, sustainable reform (Snyder, Bolin and Zumwalt 1992; Datnow, Hubbard, & Mehan, 2002). This flexible research plan also minimized any threat teachers felt from me as their department chair leading this project.

History. There are many professional development opportunities that my district offers to teachers, and teachers who are a part of my study could have experienced other meaningful conversations or support during the time of my study. In the case that this happens, one could argue that these alternative professional development opportunities or meaningful conversations, rather than my professional development program, caused improvements in teachers' skills, attitudes, and efficacy regarding inquiry (Smith & Glass, 1987). To ensure an accurate view of how teachers experienced the PD experience in the current study specifically, I measured the teachers' growth throughout the duration of the program using multiple methods and followed up the experience with interviews where I asked teachers directly about their experiences.

CHAPTER 4

RESULTS

Introduction

In this chapter I present my findings, organized by my research questions:

1. How and to what extent does an inquiry-based professional development experience influence six high school biology teachers' attitudes and perceptions regarding inquiry-based pedagogy?
2. How does an inquiry-based professional development experience affect how well six high school biology teachers implement an inquiry-based pedagogy?

RQ 1: How and to what extent does an inquiry-based professional development experience influence six high school biology teachers' attitudes and perceptions regarding inquiry-based pedagogy?

In order to answer research question 1, quantitative and qualitative data were collected and analyzed. Quantitative data included teacher surveys and the card-sorting activity. Qualitative data included individual interviews and PLC observations.

Quantitative results related to teachers' attitudes and perceptions regarding inquiry-based pedagogy. As described in the method section, a teacher survey was administered before the summer workshop and at the end of the study period, 22 weeks later. The descriptive statistics presented here help make sense of participants' responses and how they changed over the course of the study. The mean and standard deviation for each construct were calculated and are presented below in Table 5.

Table 5.

Combined Descriptive Statistics

Construct: Perception of skill using inquiry-based teaching	N	Mean	*SD*
Pre-PD	6	4.60	1.03
Post-PD	6	5.13	1.12
Construct: Perception of efficacy regarding inquiry-based teaching	N	Mean	*SD*
Pre-PD	6	4.47	1.33
Post-PD	6	5.10	1.29
Construct: Attitude toward using inquiry-based teaching	N	Mean	*SD*
Pre-PD	6	4.33	0.63
Post-PD	6	4.67	0.74

It is clear from the data presented in Table 5 that the mean scores increased for each construct from pre- to post- PD experience. Next, a paired-samples *t*-test allowed me to compare the mean scores to establish whether the differences were statistically significant. The paired samples *t*-test results are presented below in Table 6.

Table 6.

Paired Samples t-Test Paired Differences

Construct: Perception of skill using inquiry-based teaching	Mean	*SD*	Significance
Pre – Post Difference	0.53	0.50	0.048*
Construct: Perception of efficacy regarding inquiry-based teaching	Mean	*SD*	Significance
Pre – Post Difference	0.63	0.48	0.023*
Construct: Attitude toward using inquiry-based teaching	Mean	*SD*	Significance
Pre – Post Difference	0.33	0.39	0.093

*Significant at p <.05

The data in Table 6 indicate that the differences from pre- to post- scores for the first two constructs, perception of skills using inquiry-based teaching and perception of efficacy regarding inquiry-based teaching, were significant. Although differences from pre- to post- were not significant for the construct that measured attitude toward using inquiry-based teaching, the data suggest that teachers' attitudes still improved somewhat over the course of the study.

In addition to the teacher survey, the card sorting task was also administered before the summer workshop and at the end of the study period. Teachers were asked to sort a stack of 20 descriptions of hypothetical activities they could use in their classrooms into one of two piles signifying them as either being activities they would or would not use as a teacher. The activities were grouped into three sub-constructs: student-centered, activity-centered, and teacher-centered. The descriptive statistics presented here help make sense of the participating teachers' choices and how they changed over the course of the study. The mean and standard deviated for each construct were calculated and are presented below in Table 7.

Table 7

Card Sorting Activity Descriptive Statistics by Sub-Construct

Construct: Student-Centered Items	N	Mean	*SD*
Pre-PD	6	4.67	0.516
Post-PD	6	4.33	0.816
Construct: Activity-Centered Items	N	Mean	*SD*
Pre-PD	6	4.50	1.64
Post-PD	6	4.83	1.16
Construct: Teacher-Centered Items	N	Mean	*SD*
Pre-PD	6	3.33	1.37
Post-PD	6	2.17	1.33

The data presented in Table 7 reveals a slight decrease in the frequency of teachers choosing student-centered items from pre- to post, a slight increase in teachers choosing activity-centered items from pre- to post, and a more substantial decrease in teachers choosing teacher-centered items from pre- to post. Next, a paired-samples *t*-test allowed me to compare the mean scores from pre- to post- to establish whether the differences were statistically significant. The results of the paired samples *t*-test are presented below in Table 8.

Table 8

Paired Samples t-Test Paired Differences

Construct: Student-Centered Items	Mean	*SD*	Significance
Pre – Post Difference	0.333	.516	0.175
Construct: Activity-Centered Items	Mean	*SD*	Significance
Pre – Post Difference	-0.333	1.633	0.638
Construct: Teacher-Centered Items	Mean	*SD*	Significance
Pre – Post Difference	1.167	0.753	0.013*

*Significant at $p < .05$

The data in Table 8 indicate that the differences from pre- to post- scores for the first two variables, student-centered items, and activity-centered items, were not significant, as their significance values were $p > .05$. The frequency of teachers choosing teacher-centered items, however, was significantly reduced after the PD experience ($p = .013$). The differences exhibited in Table 8 along with other nuances in the card sorting data are discussed further in Chapter 5.

Qualitative results related to teachers' attitudes and perceptions regarding inquiry-based pedagogy. At the end of the entire PD experience, I conducted individual teacher interviews intended to gather information regarding both of my research questions. As described in chapter 3, I grouped my theory-driven, hypothesis codes into two larger categories dealing with *teachers' attitudes and perceptions* regarding inquiry-based pedagogy and the *structure of the PD experience*, and created an additional category with inductive, data driven codes for data that did not fit into the other theory-driven categories called *challenges*. This third category, *challenges*, will be discussed in chapter 5. The categories dealing with *teachers' attitudes and perceptions* regarding inquiry-based pedagogy and *the structure of the PD experience* provided data regarding RQ 1 and will be discussed here.

To provide data about whether the summer workshop and subsequent semester of PLCs was effective in transforming the participating teachers' attitudes and perceptions of inquiry, I asked teachers what they felt were the strengths and challenges of inquiry and whether the entire PD experience changed their thinking or attitudes about this at all.

When asked about the strengths of inquiry, all participants mentioned key aspects of inquiry-based pedagogy as described by the National Research Council in the *National Science Education Standards* (NRC, 1996), *Arizona Collaborative for Excellence in the Preparation of Teachers* (Piburn & Sawada, 2000), and *Project 2016: Science for All Americans: A project 2061 Report on Literacy Goals in Science, Mathematics, and Technology* (AAAS, 1989). One participating teacher described the strengths of inquiry this way:

Well the strengths of inquiry are that it forces kids to think deeply about material.

They have to make decisions. They have to employ the scientific method and I think they learn more when they're having to, even if it's something like a guided inquiry lesson, like the POGIL assignments, where they have to scrutinize a model. And decide what the model is showing. And answer questions based on what decisions they've made. It makes a big difference. Also, when you have kids working in groups, and they're using inquiry methods. Then they converse with each other and they have to, like I'll hear kids making an argument for this or making an argument for that. And I really do think that they learn the material better when they have to make decisions about stuff. Also, when you do a true inquiry lab and the kids get results at the end and they have to make sense of them, then they're really using the concepts of biology. They're not just learning it from, or memorizing it from a lecture or something.

Embedded in this answer is an emphasis on the importance of students explaining and justifying their work to themselves and one another (NRC, 1996, pg. 33; Piburn & Sawada, 2000), modeling the skills of scientific inquiry as well as openness to new ideas and data, and the skepticism that characterizes science (NRC, 1996, pg. 32; Piburn & Sawada, 2000), and collecting and using evidence. This answer demonstrated to me that this particular teacher had developed very positive attitudes and perceptions of inquiry-based pedagogy and an understanding of why and how this method of instruction benefits students.

Another participant described the strengths of inquiry in this way:

What I like the best with inquiry is that, for example, the two labs that we did this semester for their final exam, we did the potato lab and the Egeria lab, and they *are both based off of osmosis, but they didn't know what osmosis was, like I had not introduced that term. So, what's happening is we're just, "Hey, let's try this" and then something happens and it becomes, "Why did that happen?" Rather than saying, "this is a thing, here's a demonstration." It sort of mimics the way that it occurs in reality where you see a phenomenon that you don't understand and then you try to figure out why it's happening. You investigate, and then you do research and you come up with the whole "cause that's how actual science is done, you know" I like that aspect.*

Rooted in this response is an understanding of the importance of starting with questions about nature and engaging students actively (NRC, 1996, pg. 30; Piburn & Sawada, 2000), and encouraging and modeling the skills of scientific inquiry (NRC, 1996, pg. 32; Piburn & Sawada, 2000).

After analyzing the frequency of various codes in each of the participants' interviews I discovered that all of the participants had included at least two of the over-arching themes of teaching pedagogy consistent with the nature of scientific inquiry (AAAS, 1989, NRC, 1996, Piburn & Sawada, 2000) in their response to the question regarding the strengths of inquiry.

When I asked teachers whether the entire PD experience changed their thinking or attitudes about inquiry-based pedagogy, all teachers reported the experience did reinforce or positively influence their thinking and attitudes about inquiry. One participating teacher stated:

Um you know, it [the workshop and subsequent follow up PLCs] made me more aware of it I think. When we get in the thick of things and you are busy with

> *emails, parent interactions, kids who need tutoring, and lesson planning, you can be like, "Oh you know what, I am just going to deliver a lecture on this because it is easier." But having the focus of the workshop and knowing that you were going to be requesting that you come for a visit when we were doing inquiry lessons, it made me think more about how I could incorporate inquiry.*

Similarly, when asked whether the entire PD experience changed their thinking or attitudes about inquiry-based pedagogy another teacher stated:

> *Yes. The workshop that you did over the summer reinforced my ideas about inquiry. I felt that if done properly and really well planned, inquiry lessons could make ideas that may seem abstract to some students seem more concrete. That surprised me when we did the workshop this summer. Some of those ideas you might even learn in a college calculus class, but yet it was simplified in a way that was tangible and easier to understand. What the workshop did for me was show me that inquiry could be very highly effective if done properly.*

Further, all of the teacher participants reported that in particular, the structure of the PD experience, informed by ideas from transformative learning (Davis, 2006; Mezirow, 1998; Taylor, 2008), adult learning theory (Speck, 1996), and mutual adaptation (Berman & McLaughlin, 1978; Snyder, Bolin, and Zumwalt, 1992; Datnow, Hubbard, & Mehan, 2002), was useful in transforming their attitudes and perceptions regarding inquiry-based pedagogy. The most frequently mentioned code, which all participants mentioned at least once, was the benefit of having the chance to reflect, share, and generalize learning. I intentionally integrated these opportunities for reflection and sharing, informed by Speck (1996), into the PD experience through the weekly PLC follow up and support in hopes that the teachers would be more likely to transfer the learning into practice. Below are three quotes from the interviews that exemplify the benefit of having the opportunity to reflect and share with the group during PLCs:

> *I think it was really helpful bouncing ideas off of people and learning ways that they do stuff has been really beneficial, on top of, I've been able to share quite a bit with others in my PLC. And I think we've seen a lot of success from that collaboration with each other.*
>
> *When everybody's doing it, we have a bigger pool of, I guess, data, not always like quantitative data, but experiences that we can draw upon and we can collaborate on it and there's encouragement from everybody else if something goes wrong.*
>
> *You know, it's okay to try something and fail because someone else might have tried it and done well and you can point out what's different and it ends up being better overall.*

These excerpts demonstrate how the participants valued receiving support from peers and having opportunities for feedback, practice, and follow up support and coaching (Speck, 1996), and appreciated having the opportunity to participate in discourse (Davis, 2006; Mezirow, 1998; Taylor, 2008).

The interviews also revealed teachers appreciated the freedom to negotiate and adjust the innovation and recognized and benefited from learning from each other's slight differences in approach to implementing inquiry in their classrooms. One teacher who integrates more modeling into her approach stated, "How can we have students figure out DNA structure? Well we can't do that with our lab facilities, so I have to use a model there." Another teacher mentioned teachers' modified approaches in her interview as well:

> *It's good seeing a different point of view from him because he does more real world applied stuff, like here's examples from the real world, and connects things to examples from the real world that are small scale, which is nice because I can see some that I can incorporate. Like the pistol shrimp and stuff, I've stolen from him, which is cool because I don't do any of that kind of stuff. It's good to have the experiences of others. Some have more of a modeling point of view, so it's neat to see it from that point of view. I guess I do more inquiry than some of the others do, so it makes me feel a little more actually surprisingly like I want to do more.*

Other teachers discussed the benefit of having the PLCs to help brainstorm ways of simplifying labs for lower level students and in very large classes. One teacher described it this way:

> *What helped me with the PLCs is being able to brainstorm ways of still doing more complicated labs in a simpler way and still having the inquiry part of it. Being able to modify. Starting with something but then being able to modify it. I could bounce ideas off of the group and figure out, without getting rid of the labs, how I can still incorporate these ideas and still get and promote thought so to make it interesting.*

Another described the freedom to modify labs in his interview as well:

> *I think, me doing the demos, I like that just because I really feel like I'm getting way more involvement when I do a demo in my classes with the numbers and with*

the kids that I have, especially in the co-taught classes, because if I'm doing it and it's coming out the way it's supposed to come out, the kids are like, "That's cool." They can see it. I would do a demo and I would ask the questions as I'm doing it, but I think I get more out of kids that way.

These quotes are reminiscent of Berman and McLaughlin's (1978) ideas about the benefit of allowing for mutual adaptation of an innovation. Although these teachers adapted the traditional inquiry learning cycle method we covered in the summer workshop to fit their own classrooms and frames of reference, I believe this was critical for successful and sustainable reform.

Taken together, the interview data presented in this section indicates that the summer workshop and subsequent semester of PLCs was effective in transforming the participating teachers' attitudes and perceptions of inquiry. All of the teacher participants discussed at least two of the over-arching themes of teaching pedagogy consistent with the nature of scientific inquiry, reported the PD experience reinforced or positively influenced their thinking and attitudes about inquiry, and explained that the structure of the PD experience, informed by ideas from transformative learning, adult learning theory, and mutual adaptation, was instrumental in transforming their attitudes and perceptions regarding inquiry-based pedagogy.

Beyond the individual interviews, I also gathered qualitative data throughout the 18 weeks' worth of follow up PLCs through the use of field notes. The major theme that emerged early on in these PLC meetings and persisted throughout the year was: *a clear commitment by the group to keep inquiry-based pedagogy at the center of any other task we were asked to do*.

Early on in the school year, our school administrators established a goal for the PLCs to work on throughout the year: develop common unit plans that focus on essential standards and include formative assessments that provide immediate feedback and allow for reflection, adjustment, and discussion within PLCs about best practice. At the end of the summer workshop, a goal we set as a biology PLC was to re-organize particular units so that more concrete topics, which can readily be understood by students in terms of familiar observations and examples, were covered before ones that were more abstract, where student understanding could not be simply acquired through direct experiences. What ended up playing out throughout the 18 weeks of PLC follow up was a focus on a combination of district and PLC goals and a commitment to inquiry despite occasional frustrations among teachers as new initiatives or directives from the district office were introduced, and class sizes grew to nearly unmanageable sizes.

Regularly during the PLC meetings, I witnessed teachers taking the first ten or so minutes to vent about issues they were facing in their classrooms that were making carrying out the inquiry-based activities they had planned difficult. Many teachers experienced their classes swelling to 35-40 students. Honors teachers dealt with students who were ill-prepared for the level of rigor in their classes because of the removal of pre-requisite courses within our district. Co-taught teachers dealt with students who regularly missed lab days and lacked an interest and motivation in school. Despite these issues, I witnessed teachers in the PLC listen to each other, offer support, and provide suggestions to one another of how they were dealing with similar issues, even if this meant veering from pure inquiry. Often teachers discussed modifications that guided students more, or integrated concepts from modeling when complete inquiry was a bit unrealistic for certain topics. A commitment to maintaining the type of instruction we had decided was crucial for students in the face of issues that were outside of our control developed a comradery and actually appeared to motivated teachers to work even harder.

This freedom to adapt inquiry to what would realistically work in the participating teachers' teaching environments was evocative of mutual adaptation (Berman & McLaughlin, 1978). The freedom to negotiate the innovation appeared to encourage teachers to continue working toward the ideals they had set during the summer workshop even when the realities of teaching in a public high school in Arizona felt like they were getting in the way. Further, my observations of the transformative conversations that took place from week to week in terms of working through issues and frustrations with support and guidance from peers resembled what Speck (1996) discussed in terms of the way adults learn and transfer new ideas into practice.

In terms of the work we were asked to do by our administrators, the unit plans we developed to satisfy school requirements actually served as a useful template in deciding what concepts and understandings were truly essential for students to leave biology with. In each unit, the biology teachers identified overarching understandings that contributed to students' ability to think critically and solve problems. In generating formative assessments, teachers were able to generate and experiment with lab extensions and also develop questions that provided teachers with information about their students' reasoning patterns and allow students to have consistent practice and guidance in developing new reasoning patterns.

The participating teachers' dedication to inquiry-based pedagogy through the semester was a clear indication that their attitudes and perceptions regarding inquiry were overwhelmingly positive. The comradery that was developed through the ability to discuss, reflect, share, and modify inquiry to a format that fit their teaching environments helped sustain the innovation far beyond the summer workshop.

Summary of data analysis and results for RQ 1: How and to what extent does an inquiry-based professional development experience influence six high school biology teachers' attitudes and perceptions regarding inquiry-based pedagogy? In order to answer RQ 1, quantitative and qualitative data were collected and analyzed. Quantitative data from the teacher surveys and the card-sorting activity indicated the participating teachers improved their attitudes and perceptions regarding inquiry throughout the course of the study. The survey data revealed that the teachers significantly improved their perception of skills using inquiry-based teaching and perception of efficacy regarding inquiry-based teaching. The survey data also showed that teachers' attitude toward using inquiry-based teaching improved over the course of the study, although the improvement was not statistically significant. The card sorting data demonstrated the frequency of teachers choosing teacher-centered items as activities was significantly reduced after the PD experience. The qualitative data from individual interviews and PLC observations support the assertion from the quantitative data that teachers' attitudes and perceptions regarding inquiry improved over the course of the study. Further, the qualitative data point to the qualities of adult learning theory, as informed by Speck (1996), and mutual adaptation, informed by Berman and McLaughlin (1978), that were embedded into the PD experience as particularly useful in improving teachers' attitudes and perceptions and sustaining the innovation.

RQ 2: How does an inquiry-based professional development experience affect how well six high school biology teachers implement an inquiry-based pedagogy?

In order to answer research question 2, quantitative and qualitative data were collected and analyzed. Quantitative data included classroom observations using RTOP. Qualitative data included individual interviews.

Quantitative results related to teachers' skills in implementing inquiry-based pedagogy. During the fall semester following the summer workshop, the RTOP protocol was used to conduct three observations of each participating teacher in order for me to understand how effectively teachers were using inquiry in their classrooms. RTOP is organized in five sub-constructs: *lesson design and implementation*, *propositional knowledge, procedural knowledge, communicative interactions*, and *student/teacher relationships*. For each observation, teachers earned scores for each sub-construct area as well as a total score.

The mean and standard deviation for each sub-construct along with the total score for each observation were calculated and are presented below in Table 9. You will notice there were only 5 participants' scores recorded for observation 2, this was due to the fact that one teacher was out on maternity leave for a portion of the semester and was only able to be observed twice.

Table 9

Descriptive Statistics for Sub-Construct Area and Total Score for RTOP

Sub-Construct	Observation 1	Observation 2	Observation 3
Sub-Construct 1: Lesson Design and implementation			
Mean	9.67	10.80	15.50
Standard Deviation	3.5	4.70	3.27
N	6	5	6
Sub-Construct 2: Propositional Knowledge			
Mean	10.67	12.80	16.50
Standard Deviation	3.27	3.27	3.21
N	6	5	6
Sub-Construct 3: Procedural Knowledge			
Mean	8.33	9.60	12.50
Standard Deviation	4.23	4.77	2.07
N	6	5	6
Sub-Construct 4: Communicative Interactions			
Mean	9.83	11.60	15.50
Standard Deviation	3.49	3.65	1.38
N	6	5	6
Sub-Construct 5: Student/Teacher Relationships			
Mean	12.5	13.2	17.5
Standard Deviation	2.59	4.14	2.88
N	6	5	6
Total Aggregate Constructs			
Mean	51.00	58.80	78.17
Standard Deviation	15.59	19.64	10.80
N	6	5	6

The data presented in Table 9 reveals teachers showed improvement in each of the five sub-constructs and the total score with each observation. Because teachers were observed three times throughout the study, I created six charts, one for each of the five sub-constructs and one for the total aggregate constructs, to illustrate the growth trajectory for each teacher over the three observations. Each chart includes a trend line for each teacher as well as one for the aggregate average. Additionally, I created tables that include the data that each chart displays. I chose to illustrate the growth trajectory for each teacher rather than use hypothesis testing because visualizing the growth trajectory presents a more relevant and understandable measure of efficacy for my intended audience of K-12 teachers and administrators.

Figure 1 and Table 10 below display each participating teacher's score, and the aggregate average for the first sub-construct included in RTOP, *lesson design and implementation*.

Figure 1

RTOP Scores Sub-Construct 1: Lesson Design and Implementation

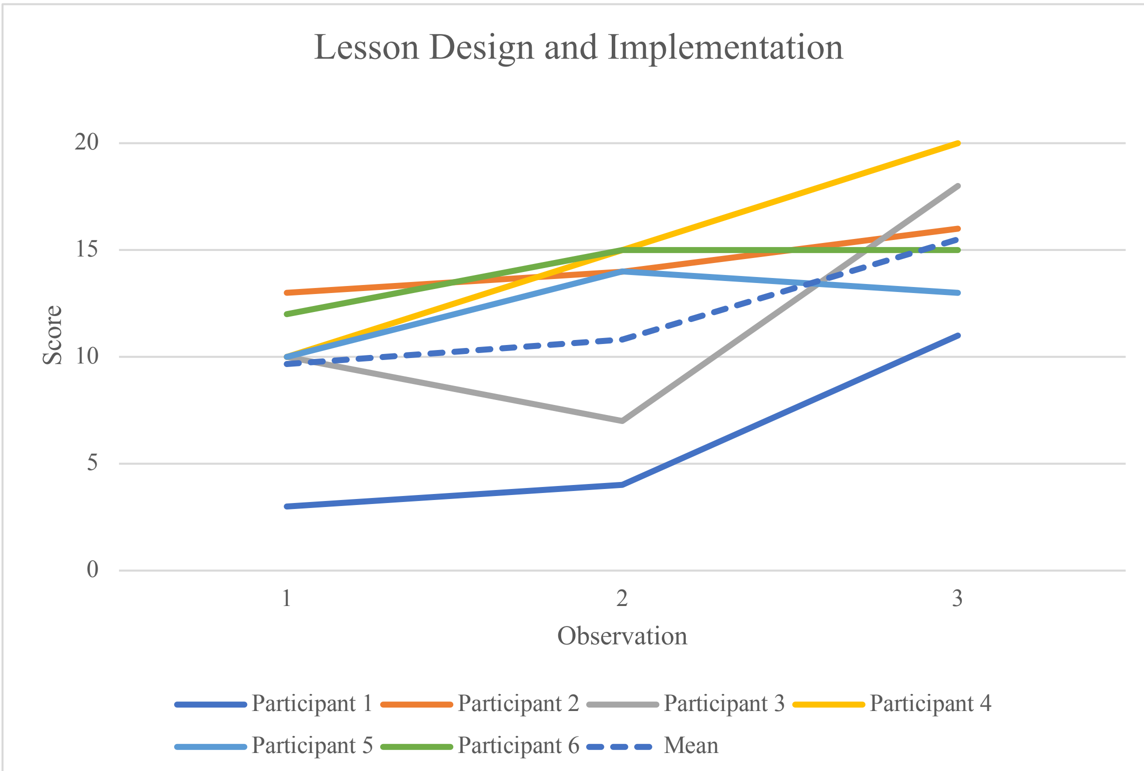

Table 10

RTOP Scores Sub-Construct 1: Lesson Design and Implementation

Participant	Observation 1 Score	Observation 2 Score	Observation 3 Score
1	3	4	11
2	13	14	16
3	10	7	18
4	10	-	20
5	10	14	13
6	12	15	15
Mean	9.67	10.80	15.50

From the data displayed in Figure 1 and Table 10, it is clear that most teachers showed consistent improvement in their lesson design and implementation throughout the semester. Although participant 3 saw a slight decrease on the second observation followed by a substantial increase on the third observation, and participant 5 saw a slight decrease on the final observation after increasing from the first observation to the second, the overall mean demonstrates a substantial increase throughout the course of the study in terms of construct 1: lesson design and implementation.

Figure 2 and Table 11 below display each participating teacher's score, and the aggregate average for the second sub-construct included in RTOP, *propositional knowledge*.

Figure 2

RTOP Scores Sub-Construct 2: Propositional Knowledge

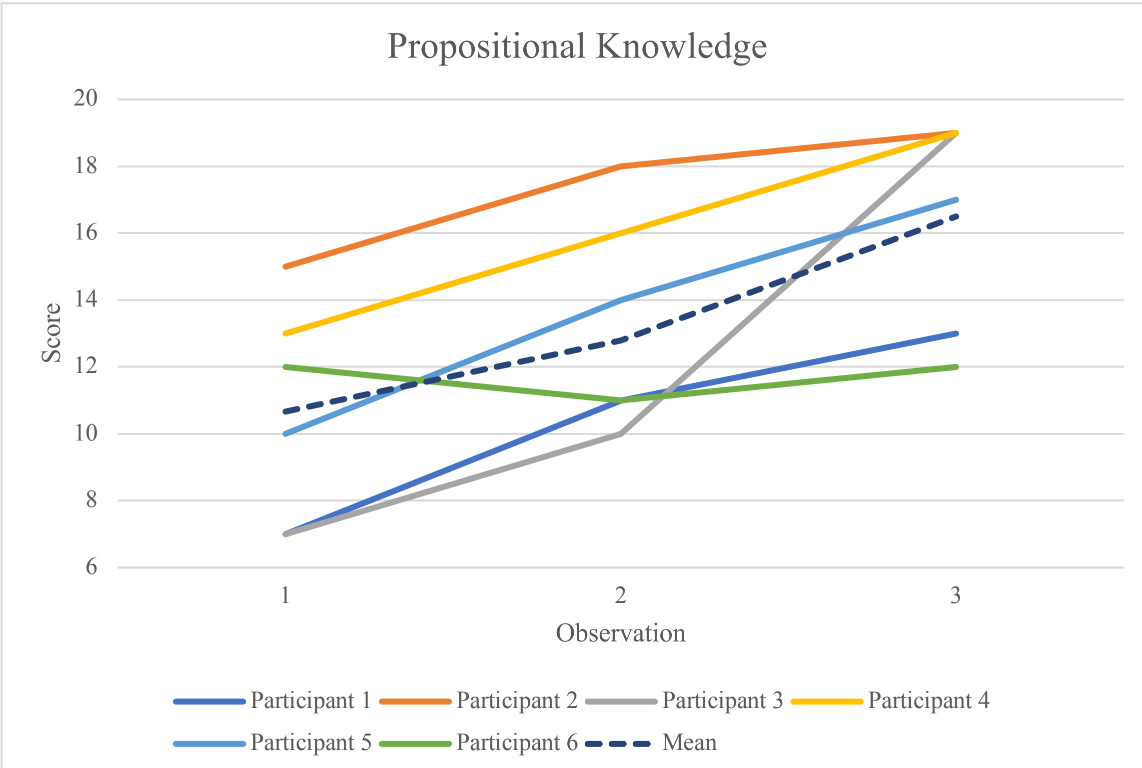

Table 11

RTOP Scores Sub-Construct 2: Propositional Knowledge

Participant	Observation 1 Score	Observation 2 Score	Observation 3 Score
1	7	11	13
2	15	18	19
3	7	10	19
4	13	-	19
5	10	14	17
6	12	11	12
Mean	10.67	12.8	16.5

From the data displayed in Figure 2 and Table 11, it is clear that most teachers showed consistent improvement in their propositional knowledge throughout the semester. The propositional knowledge sub-construct of RTOP spotlights the significance and abstraction of the content, how well the teacher understands it, and any connections established between the content of the lesson and other disciplines and real life (Piburn & Sawada, 2000). Although participant 6 saw a slight decrease on the second observation followed by an increase on the third observation, the overall mean demonstrates a substantial increase throughout the course of the study in terms of sub-construct 2: *propositional knowledge*.

Figure 3 and Table 12 below display each participating teacher's score, and the aggregate average for the third sub-construct included in RTOP, *procedural knowledge*.

Figure 3

RTOP Scores Sub-Construct 3: Procedural Knowledge

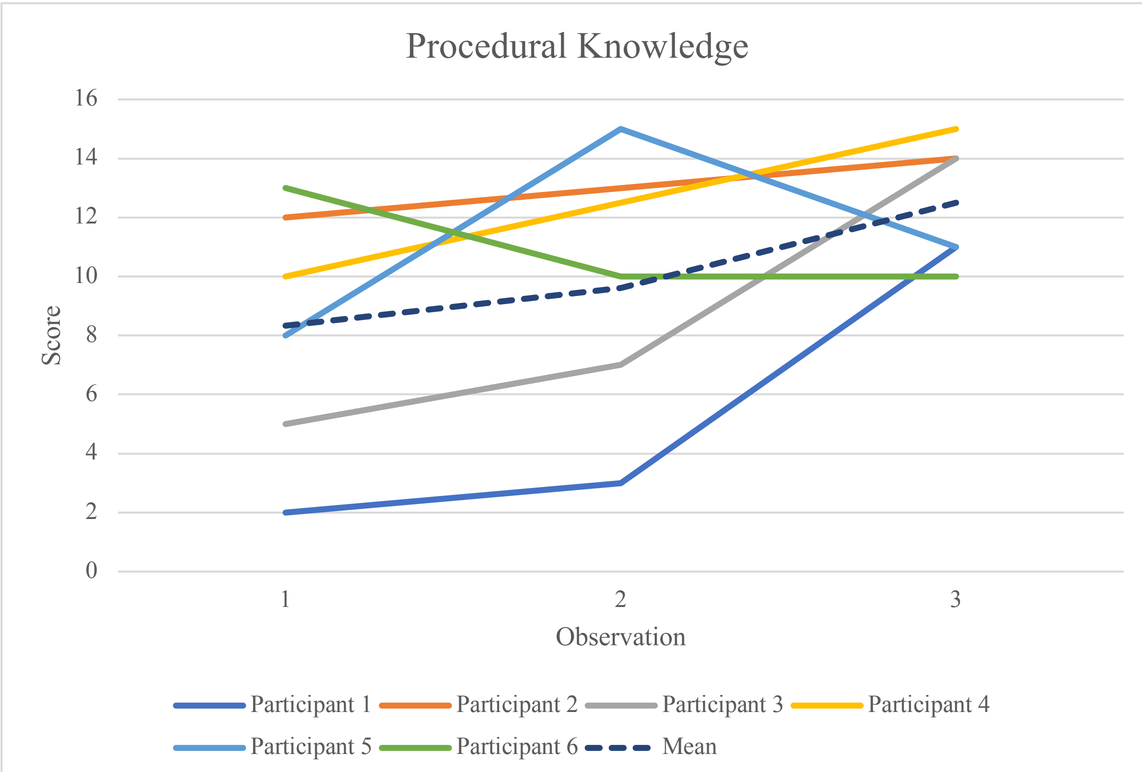

Table 12

RTOP Scores Sub-Construct 3: Procedural Knowledge

Participant	Observation 1 Score	Observation 2 Score	Observation 3 Score
1	2	3	11
2	12	13	14
3	5	7	14
4	10	-	15
5	8	15	11
6	13	10	10
Mean	8.33	9.6	12.5

The data displayed in Figure 3 and Table 12, displays how most teachers showed consistent improvement in their procedural knowledge throughout the semester. Procedural knowledge focuses on the kinds of processes that teachers ask students to use to manipulate information, draw conclusions, and evaluate claims (Piburn & Sawada, 2000). This sub-construct most closely resembles what is commonly referred to as scientific reasoning (Piburn & Sawada, 2000). Participant 5 had a slight decrease in score from observation 2 to observation 3, but the score for observation 3 was still higher than for observation 1. Also, the score for participant 6 did not show improvement from the second observation to the third. As a whole, however, the overall mean demonstrates a substantial increase throughout the course of the study in terms of sub-construct 3: *procedural knowledge*.

Figure 4 and Table 13 below display each participating teacher's score, and the aggregate average for the fourth sub-construct included in RTOP, *communicative interactions*.

Figure 4

RTOP Scores Sub-Construct 4: Communicative Interactions

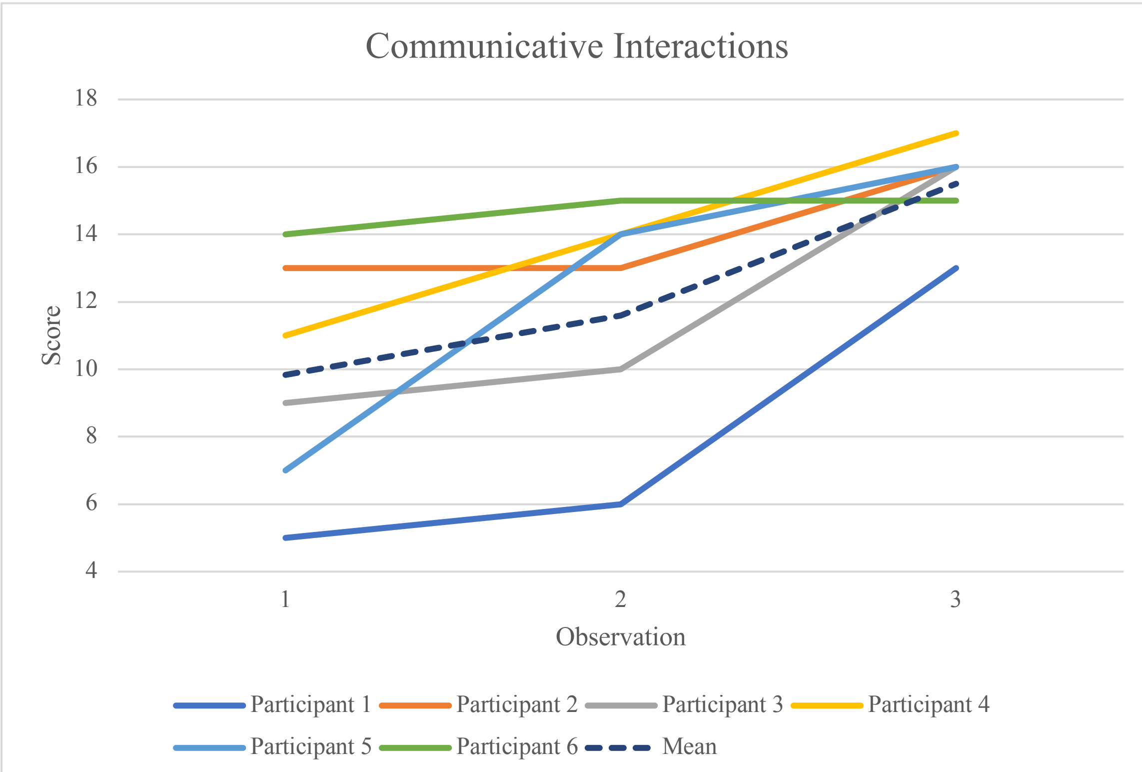

Table 13

RTOP Scores Sub-Construct 4: Communicative Interactions

Participant	Observation 1 Score	Observation 2 Score	Observation 3 Score
1	5	6	13
2	13	13	16
3	9	10	16
4	11	-	17
5	7	14	16
6	14	15	15
Mean	9.83	11.6	15.5

The data displayed in Figure 4 and Table 13, demonstrates how all teachers showed consistent improvement in their communicative interactions throughout the semester. The communicative interactions sub-construct of RTOP focuses on the nature of communication between students, as well as with the teacher (Piburn & Sawada, 2000). Lessons where teachers characteristically speak and students listen are not indicative of inquiry-based curricula (Piburn & Sawada, 2000). Although participant 2 did not show an increase from observation 1 to observation 2, and participant 6 did not show an increase from observation 2 to observation 3, the overall mean demonstrates a substantial increase throughout the course of the study in terms of sub-construct 4: *communicative interactions*.

Figure 5 and Table 14 below display each participating teacher's score, and the aggregate average for the fifth sub-construct included in RTOP, *student/teacher relationships*.

Figure 5

RTOP Scores Sub-Construct 5: Student/Teacher Relationships

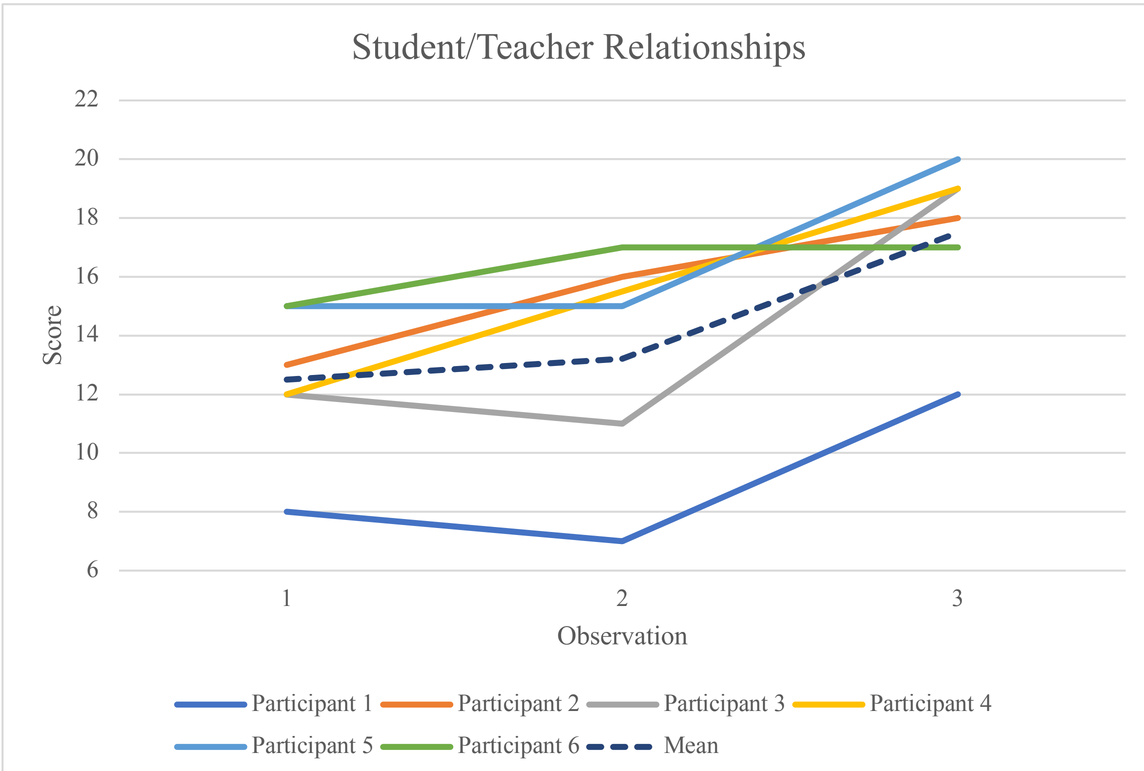

Table 14

RTOP Scores Sub-Construct 5: Student/Teacher Relationships

Participants	Observation 1 Score	Observation 2 Score	Observation 3 Score
1	8	7	12
2	13	16	18
3	12	11	19
4	12	-	19
5	15	15	20
6	15	17	17
Mean	12.5	13.2	17.5

The data displayed in Figure 5 and Table 14, demonstrates how all teachers showed consistent improvement in their student/teacher relationships throughout the semester. The student/teacher relationships sub-construct of RTOP evaluates the extent to which students have a voice in how activities occur and undertake scientific thought and problem solving (Piburn & Sawada, 2000). Although participant 3 had a slight decrease in their score on observation 2 before substantially improving in observation 3, participant 5 did not show an increase from observation 1 to observation 2, and participant 6 did not show an increase from observation 2 to observation 3, the overall mean demonstrates a substantial increase throughout the course of the study in terms of sub-construct 5: *student/teacher relationships*.

Figure 6 and Table 15 below display each participating teacher's total score for each observation, the aggregate of all sub-constructs.

Figure 6

RTOP Scores: Total Aggregate Sub-Constructs

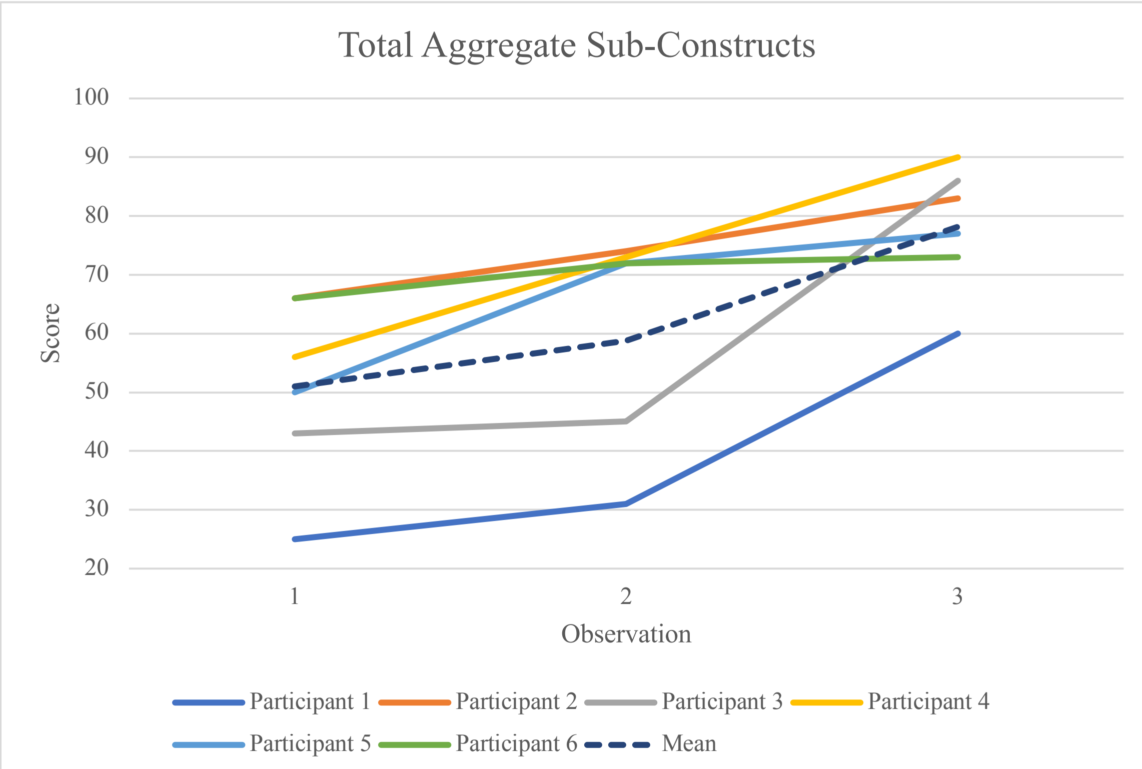

Table 15

RTOP Scores: Total Aggregate Sub-Constructs

Participant	Observation 1 Score	Observation 2 Score	Observation 3 Score
1	25	31	60
2	66	74	83
3	43	45	86
4	56	-	90
5	50	72	77
6	66	72	73
Mean	51.0	58.80	78.17

The data displayed in Figure 6 and Table 15 suggests an ongoing improvement in the teachers' ability to use inquiry in their classrooms throughout the semester following the summer workshop, as they received follow up support in their weekly PLC meetings.

Taken together, the quantitative data gathered from the classroom observations using RTOP suggest the PD experience was effective in facilitating improvement in the participating teachers' skills using inquiry in their classrooms. To develop a more holistic understanding of how and why this improvement occurred, analysis of individual teacher interviews will be discussed in the following section.

Qualitative results related to teachers' skills in implementing inquiry-based pedagogy. In order to learn more about how the PD experience influenced the participating teachers' skills using inquiry in their classroom, I asked teachers about their experiences teaching inquiry labs in their classrooms, moments they were proud of, and how the PLC helped support their efforts in teaching inquiry. The responses to these questions related to the broader themes regarding *teachers' attitudes and perceptions* and the *structure of the PD experience,* and provide insight into how the teachers improved their skills using inquiry in their classes.

When I asked teachers about their experiences teaching inquiry labs in their classrooms and moments they were proud of, all teachers described lessons that included key aspects of inquiry-based pedagogy as described by the National Research Council in the *National Science Education Standards* (NRC, 1996), *Arizona Collaborative for Excellence in the Preparation of Teachers* (Piburn & Sawada, 2000), and *Project 2016: Science for All Americans: A project 2061 Report on Literacy Goals in Science, Mathematics, and Technology* (AAAS, 1989). For example, one participating teacher stated:

> *One of the most common things that students say they like about the way I teach is that I don't give them the answers and I just lead them to the answer by asking questions. When I had the intern, I used the metaphor of personal training. So it's like when someone's lifting weights, you're there to spot them, but you don't lift the weight for them. They aren't going to get anything out of it if you lift the weight for them, but you want to be there to help if they're struggling with it or if they can't do it. It's the same way with teaching. I'm not giving them the answer because they don't benefit from that at all. But helping guide them to the answer and then giving them a lot of guidance if they need it gets them to where they want to be and actually helps them build their mental capacity.*

Embedded in this answer is an emphasis on the importance about starting with questions. This is a key feature of good science teaching, in that teaching should be consistent with the nature of scientific inquiry (NRC, 1996, p. 30). Similarly, another teacher described something they were proud of this way:

> *We have flipped a lot of the labs to be before instruction, so rather than doing a lab as a follow up to teacher directed instruction, we are having the students collect the evidence and then derive formulas or come up with ideas about why things work before they're ever taught. That has probably been the best result from all of this.*

This response demonstrates that this teacher shifted the way she thinks about constructing lessons to concentrate on the collection and use of data and evidence and modeling the skills of scientific inquiry. These are also important aspects of good science teaching that are in line with the way science is conducted (NRC, 1996, p. 30).

Through the interviews, I also wanted to gain a better understanding of how the PD experience helped support the teachers' efforts in using inquiry-based pedagogy in their classrooms. In order to gain a better understanding of how the teachers experienced the PD throughout the semester, I asked the teachers about this in the interviews. In their responses, all of the participating teachers included some aspect about how participating in discourse, receiving follow up support and coaching, or reshaping belief structures helped them improve their skills using inquiry in their classrooms. One teacher described the usefulness of the PD experience this way:

> *The fact that everybody is on the same page and that we are all working towards that same goal, with the same value system, that this is how science is done and this is how we want to teach science. We want to lead students through the experience of science rather than just sort of teaching them what scientists have done and then just expecting them to memorize it. When everybody's doing that, it makes it much, I guess, healthier.*

Another teacher described the usefulness of the PD in developing skills using inquiry this way:

> *To hear peoples' different approaches, it was also good about keeping me from slipping into the "sage on the stage." I don't want to be that kind of teacher. But when you are teaching a new course that's the quickest and easiest way to do things. And then what I'm afraid of, my dad was a teacher for 34 years and he talked about inertia and how once you get set in motion on whatever path you're on, you tend to stay on it. So if I create a PowerPoint lecture for something and*

then have a follow-up worksheet, cause that's the easy method, then I'll probably keep using it. So I didn't want to do that. I didn't even want to start going down that route. And so by working in our PLC with people who were committed to inquiry, it kept me from being lazy.

In a similar way to how the PLC was effective in transforming the participating teachers' attitudes and perceptions of inquiry, the interview data presented in this section indicates that the summer workshop and subsequent semester of PLCs was effective in supporting the improvement in teachers' skills using inquiry in their classrooms. All of the participants described lessons they conducted that included key aspects of inquiry-based pedagogy as described by the National Research Council in the *National Science Education Standards* (NRC, 1996), *Arizona Collaborative for Excellence in the Preparation of Teachers* (Piburn & Sawada, 2000), and *Project 2016: Science for All Americans: A project 2061 Report on Literacy Goals in Science, Mathematics, and Technology* (AAAS, 1989). This indicates that the teachers developed a coherent understanding of inquiry-based pedagogy and were using it in their classrooms. Additionally, the structure of the PD, including a summer workshop and follow up collaborative PLC meetings, appeared to be useful in transferring the teachers' learning into practice. All of the participating teachers discussed at some level how participating in discourse, receiving follow up support and coaching, or reshaping belief structures helped them improve their skills using inquiry in their classrooms.

It is clear from the sum of the interview data that teachers did improve in their skills regarding inquiry-based pedagogy throughout the course of the study.

Summary of data analysis and results for research question 2: How does an inquiry-based professional development experience effect how well six high school biology teachers implement an inquiry-based pedagogy? In order to answer research question 2, quantitative and qualitative data were collected and analyzed. The quantitative data, obtained through classroom observations using RTOP, indicated that the participating teachers consistently improved their skills using inquiry in their classrooms throughout the course of the study. Additionally, data from the individual interviews suggested that the total PD experience, from the initial workshop through the supporting PLC work, was effective in facilitating improvement in the participating teachers' skills using inquiry in the classroom. In particular, teachers reported that participating in discourse and receiving follow up support and coaching were especially helpful in transforming their learning into practice.

CHAPTER 5

INTERPRETATION

Introduction

Through this study, I sought to understand how teachers experience the transition to a method of instruction designed to develop critical reasoning skills. In the years leading up to the study, the science teachers in my department gradually reduced the frequency of inquiry-based laboratory activities that enable students to think in a way that contributes to their ability to reason critically. In order to address this problem, I worked with the biology teachers at my high school to co-construct a professional development experience and long-term plan to support teaching through scientific inquiry. I designed and conducted a two-day summer workshop and offered follow up support through 18 weeks' worth of PLC meetings, driven by the goals and progress of the participating teachers. Through this work I hoped to create a culture of collaboration and support among teachers that would facilitate an improvement in attitudes, perceptions, and pedagogical knowledge and skills regarding inquiry through reflection, critical thinking, and practice.

In this chapter I will discuss the interaction of the qualitative and quantitative results and how the goals of the study were met. Additionally, I will discuss how the discoveries that emerged relate back to the theoretical frameworks that centered the design of the study, and how they may inform future practice and research.

Interaction of Qualitative and Quantitative Results and Emergent Takeaways

Analysis of all data sources, including teacher surveys, the card sorting activity, classroom observations using RTOP, individual interviews, and PLC observations, suggests the PD experience tested in this study (a two-day summer workshop and 18 weeks of subsequent follow up support during PLCs) was effective in positively influencing the six high school biology teacher participants' attitudes, perceptions, and skills regarding inquiry-based pedagogy.

Quantitative data from the teacher surveys and the card-sorting activity indicated the participating teachers improved their attitudes and perceptions regarding inquiry throughout the course of the study. After participating in the PD experience, the teachers reported feeling significantly more confident in terms of their skills and efficacy in implementing inquiry-based pedagogy in their classrooms than before the intervention began. The teachers' attitude toward using inquiry-based teaching also improved over the course of the study, although the improvement was not statistically significant. After the PD experience, the card sorting data revealed the teachers chose significantly less teacher-centered activities. This finding corroborates the findings of the survey and confirms that teachers developed a better understanding of inquiry throughout the semester and positively transformed their attitudes and perceptions.

The qualitative data from individual interviews and PLC observations support the findings from the quantitative data. When asked about the strengths of inquiry, all participants described key aspects of inquiry-based pedagogy as described by the National Research Council in the *National Science Education Standards* (NRC, 1996), *Arizona Collaborative for Excellence in the Preparation of Teachers* (Piburn & Sawada, 2000), and *Project 2016: Science for All Americans: A project 2061 Report on Literacy Goals in Science, Mathematics, and Technology* (AAAS, 1989).

Beyond attitudes and perceptions of inquiry-based pedagogy, the ability of the participating teachers to implement an inquiry-based pedagogy in their classrooms was significantly improved throughout the semester as well. The quantitative data, collected through classroom observations using RTOP, demonstrated that the participating teachers consistently improved their skills using inquiry in their classrooms throughout the course of the study. The ability of the teachers to continue to improve throughout the semester in all sub-constructs – *lesson design and implementation*, *propositional knowledge*, *procedural knowledge*, *communicative interactions*, and *student/teacher relationships* – suggests the follow up support during PLCs was particularly helpful in sustaining the innovation and deepening the level of investment. Had the summer workshop been a one-shot treatment, as so many professional development programs are, the participants would have not likely continued to improve from week to week, as was observed in this study. The data from the individual interviews substantiated the idea that the PD experience was effective in facilitating improvement in the participating teachers' skills using inquiry, and that the structure of the PD, including the PLC support, was critical in facilitating continuous improvements in skills. In particular, teachers reported that participating in discourse, receiving follow up support and coaching, and having some freedom to adjust the innovation to fit their own teaching styles were especially helpful in transforming their learning into practice in a way that was sustainable.

The sum of the data collected throughout the study demonstrate the success of the PD experience in positively influencing the attitudes, perceptions, and skills of the participating teachers. Several themes emerged as critical to the success of the professional development. Namely, the integration of qualities of Adult Learning Theory and transformative learning in the PD experience, as well as encouraging mutual adaptation of the innovation by the participating teachers, surfaced as important to making the PD experience successful.

Connections to Theoretical Frameworks

Incorporating aspects of adult learning theory, transformative learning, and mutual adaptation into the design of the PD experience emerged as germane to the sustained improvements in teacher attitudes, perceptions, and skills with inquiry-based pedagogy. Informed by the broader literature about how adults learn, I intentionally structured the PD experience to include qualities of transformative learning (Davis, 2006; Mezirow, 1998; Taylor, 2008), adult learning theory (Speck, 1996), and mutual adaptation (Berman & McLaughlin, 1978; Snyder, Bolin, and Zumwalt, 1992; Datnow, Hubbard, & Mehan, 2002). The following sections will outline how these theoretical frameworks played out in the research and contributed to the participating teachers' success.

Pertinence of adult learning theory. Informed by Speck (1996), I deliberately integrated opportunities for reflection, sharing, practice, and coaching into the PD experience through the weekly PLC follow up and support to facilitate the teachers' ability to sustainably transfer the learning into practice. The RTOP observation data suggests the teachers greatly improved their skills using inquiry-based pedagogy over the course of the study and the survey and card-sorting data indicate teachers' attitudes and perceptions of inquiry evolved as well. The interview data reveals that regular meetings and opportunities to discuss and reflect on classroom practices as well as opportunities to develop inquiry-based activities with other teachers was beneficial in motivating teachers and keeping them on track.

During the interviews all of the participating teachers described how the structure of the PD experience was useful in transforming their attitudes, perceptions, and skills regarding inquiry-based pedagogy. The most commonly occurring code in the interviews, which all participants mentioned at least once, was the benefit of having the chance to reflect, share, and generalize learning. Teachers also described how having support from their peers, opportunities for feedback and practice, and follow up support and coaching were invaluable in supporting their efforts in implementing inquiry in their classrooms. The sum of this data suggests designing the study to incorporate tenets of adult learning theory contributed to the success of PD experience.

Germaneness of transformative learning. Teachers also demonstrated a disruption to prior understandings and a reshaping of deeply ingrained assumptions and belief structures about pedagogy and inquiry, qualities indicative of transformative learning as described by Davis (2006), Mezirow (1998), and Taylor (2008). The RTOP observation data provided evidence to support this transformation, revealing that scores improved in all sub-constructs (*lesson design and implementation*, *propositional knowledge*, *procedural knowledge*, *communicative interactions*, and *student/teacher relationships)* over the three observations. Particularly, increases in mean score in the *communicative interactions and student/teacher relationships* sub-constructs are significant because these sub-constructs focus on the nature of communication between students, as well as with the teacher, and the extent to which students influence how activities occur and work through scientific thought and problem solving (Piburn & Sawada, 2000). Making changes in these categories involve reimagining the entire structure of how a classroom is run. The improvements in the *communicative interactions* *and student/teacher relationships* sub-constructs occurred as a result of teachers shifting to act as more of a facilitator, working to support and enhance student-driven investigations. These kinds of shifts are distinctly indicative of reforming deeply ingrained belief structures. Data from the individual interviews and PLC observations suggest these changes were achieved through critical self-reflection and participating in discourse, themes drawn from Davis (2006), Mezirow (1998), and Taylor (2008). I witnessed teachers reflecting on their practice together each week during PLCs, and listened to them emphasize the value of discussing and working through struggles in their individual interviews.

Materiality of mutual adaptation. The freedom to negotiate and adjust an innovation to fit the frames of reference of particular teachers, features of mutual adaptation as described by Snyder, Bolin and Zumwalt (1992) and Datnow, Hubbard, and Mehan (2002), also emerged as instrumental to the success and sustainability of the PD experience. Data from the individual interviews revealed teachers appreciated the freedom to adapt the innovation to fit the realities of their classrooms and their personal teaching styles. The teachers also recognized each other's variances in implementing inquiry and benefited from learning from different approaches. One teacher tended to integrate more aspects of modeling into her approach. Another tended to incorporate more real world, project-based aspects to the traditional learning cycle, while others often simplified the labs to meet the needs of lower level students in very large classes. During my PLC observations I noticed that as individual teachers would share their unique approaches to implementing inquiry labs in their classrooms, others appeared encouraged and intrigued by the variability and versatility of inquiry, and its potential to work with a range of teaching styles and student populations. If I had decided to measure the fidelity of implementation according to a technical-rational, objectified standard, many of the teachers may have abandoned inquiry-based pedagogy, especially when faced with challenges like large class sizes, lower-level/un-invested students, and conflicting initiatives from district office administrators. During the interviews, all teachers mentioned at least one of these challenges, prompting the creation of a data-driven, inductive category I called challenges. Although all of the participating teachers faced challenges, the freedom to adjust the innovation to be conducive with each teacher's unique style and teaching environment, combined with the ability to discuss and work through struggles with their peers, collectively helped teachers stick with the innovation and continue to improve their skills using inquiry in their classrooms.

Summary of influences of theoretical frameworks. Overall, the data indicates that integrating facets of adult learning theory, transformative learning, and mutual adaptation into the design of the PD experience contributed to the sustained improvements in teacher attitudes, perceptions, and skills with inquiry-based pedagogy.

Recommendations for Practice

In this section I will highlight some key takeaways from the study that practitioners in the field, teacher leaders, site level or district level administrators, or professional development coordinators, may find useful in supporting teachers in their efforts to improve their practice.

Getting a group of science teachers together in the summer to engage in genuine experimentation and inquiry was extremely beneficial. The experience revitalized the teachers' enthusiasm and got everyone on same page in terms of what good science teaching looks like, how students learn, and what logical next steps needed to be taken in the following semester. Newer teachers described the experience as being eye opening but even veteran teachers reported the workshop as being beneficial and enjoyable. I recommend administrators and professional development coordinators support teachers' efforts in organizing workshops like the one I carried out in the present study and allow them to receive summer pay for their time invested in improving their practice.

For individuals looking to organize a professional development workshop for science teachers, I also recommend choosing a lab experience outside of the typical topic areas the teachers teach. Using physics labs with a group of biology teachers was effective in engaging the teachers and allowing them to experience the disequilibrium students go through during inquiry-based labs first hand. Had I chosen a biology lab, the teachers would have likely been distracted by the structure of the lab itself because they would naturally compare it to the way they teach the same topic. During the summer workshop I facilitated for this study, the teachers were engaged fully in the inquiry in the same way students are in the classroom.

So often PLC time in schools is overrun with paperwork and form-filling in an attempt to provide accountability. Throughout this study, however, I was granted some leeway by my principal and was able to use the PLC time in a way that was productive for the group of teachers I worked with. Consequently, another recommendation I have for district and site level administrators is to allow time for teachers to regularly get together and give them flexibility to use the space and time in a way that is beneficial for them. If administrators identify strong teacher leaders, assign them as mentors to other teachers within their content areas, and provide them with supports to carry out an engaging professional experience, like the summer workshop conducted in this study, this may set the foundation for professional growth. Further, if the teacher leader can provide guidance as the group sets their own goals and can encourage sharing, reflecting, and practicing the work, teachers have the potential to form strong support networks and grow their practice from the inside.

From the very beginning of the process of designing the PD experience, informed by my own experiences as a teacher and takeaways from Berman and McLaughlin's (1978) work, I understood that differences in how teachers would implement my innovation was inevitable. Variation in implementation in any school setting is unavoidable, as each teacher brings their own unique set of experiences and perspectives to their teaching. I believed adopting a mutual adaptation approach would support a more successful, sustainable reform. Evidence from the teacher interviews suggests this prediction was correct. Teachers reported that they valued the freedom to negotiate and adjust the innovation, and recognized and benefited from learning from each other's differences in approach to implementing inquiry in their classrooms. Consequently, for future professional development programs for teachers, I recommend avoiding measuring the fidelity of implementation according to a technical-rational, objectified standard and adopting a mutual adaptation approach.

Another recommendation I have for district and school administrators is set teachers up to succeed. Although budget constraints of school districts are often a result of political decisions, district administrators should do everything in their power to preserve small class sizes when it is salient to the content pedagogy. The most commonly cited challenge by the teachers I worked with was dealing with the enormous class sizes they inherited this year. Allowing students to generate their own hypotheses and design and conduct their own experiments is exponentially more difficult when the number of groups and students per group increases. This challenge ultimately led two of the teachers to revert to demonstrations for certain labs because they were uncomfortable with the safety risks posed by so many students in such tight spaces and felt they could more easily expose students to the puzzling observations they intended for them to see if they did it for them. Although this demonstration method prevented the teachers from abandoning inquiry all together, they acknowledged if their classes had been smaller they could have allowed for more authentic inquiry and experimentation to take place. Accordingly, support from district administrators and a commitment to keep class sizes reasonably sized is critical to teacher and student success in the context of scientific inquiry.

Finally, the last recommendation I have is for teachers, PD coordinators, and administrators; inquiry-based pedagogy is good for all students. Often, teachers and administrators mistakenly believe that only the brightest students can succeed in student-driven classrooms where students engage in scientific inquiry. During the final round of RTOP observations, three of the six participating teachers did slight variations of a lab they generated together. To teach the concept of mitosis, three of the teacher participants came up with an idea to have their students examine photographs of microscopic images of cells at various stages in their life cycle. Each of the three teachers who used this lab did it slightly differently, but essentially the teachers asked the students to attempt to categorize the images based on what was happening, hypothesize why they looked different from one another, and then, after students came up with the idea that the cells were in different phases, attempt to place them into a chronological order. The three classes I observed contained students of all backgrounds, gifted students, on-level students, and students with individual education plans (IEPs), and all of them were able to produce the steps of mitosis on their own. Even the co-taught sections I observed throughout the semester were engaged in the inquiry-based laboratory experiences their teachers facilitated. Student-centered learning is effective for all students, and should never be limited to gifted classrooms.

Limitations and Suggestions for Further Research

Using an action research approach in this study allowed me to better understand my school and improve its effectiveness from the inside. As insightful as the process of carrying out this study was for me, the small sample size and the study's embeddedness in the specific context of my school prevents the implications from becoming generalizable. Also, although including a control group would have afforded me more decisive evidence that it was my PD experience that contributed to the teachers' improvements in attitude, perceptions, and skills with inquiry-based pedagogy, I did not set the study up in this manner. Intentionally depriving a group of teachers of a PD experience that could potentially improve their practice and the learning in their classrooms would not be ethical for those teachers or their students. Additionally, this study was not conducted in a vacuum; it was conducted at a real, functioning, large, comprehensive high school. Throughout the course of a semester in a setting like this, there are many opportunities for professional development that may have positively influenced the participating teachers. Though this lack of a control group and controlled setting, context-specific design, and small sample size somewhat limit the applicability of this study and prevent the ability to say with absolute certainty that my PD experience alone was the sole cause for improvement among the teacher participants, the multitude of quantitative and qualitative measures that all support similar findings lend credibility to the results. Nevertheless, it may be worthwhile to use a more controlled method with a larger group of science teachers to further investigate the qualities of the PD experience that I created.

Conclusion

I set out on this doctoral journey motivated to find ways to effectively develop critical reasoning skills among high school students. I understood that an inquiry-based pedagogical approach to science teaching was an effective means to develop critical reasoning but found myself frustrated by the number of teachers who failed to allocate an adequate amount of time for genuine experimentation in science classes. To address this issue, I designed this study to explore how teachers experienced the transition to a method of instruction designed to develop critical reasoning skills in hopes of finding an effective method of improving teachers' attitudes, perceptions, and skills regarding inquiry-based pedagogy. The professional development experience I designed and tested through this study effectively facilitated the development of a culture of collaboration and support among teachers. This supportive PD experience improved attitudes and perceptions of inquiry and allowed for the construction of inquiry-based pedagogical knowledge and skills through reflection, critical thinking, and practice. It is my hope that the students of the teachers who participated in this PD experience not only gained a better understanding of how the world works, but are now better prepared to think critically and solve the problems of the future.

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APPENDIX A

SURVEY INSTRUMENT

Inquiry Survey

For each question:
1=Strongly Disagree
2=Disagree
3=Slightly Disagree
4=Slightly Agree
5=Agree
6=Strongly Agree

CONSTRUCT 1: Perception of skills using inquiry-based teaching

1. **I can use inquiry-based teaching methods in my own classroom.** *
Mark only one oval.

	1	2	3	4	5	6	
Strongly Disagree	◯	◯	◯	◯	◯	◯	Strongly Agree

2. **I can create inquiry-based lab activities for use in my own classroom.** *
Mark only one oval.

	1	2	3	4	5	6	
Strongly Disagree	◯	◯	◯	◯	◯	◯	Strongly Agree

3. **I can carry out inquiry-based lab activities in my own classroom.** *
Mark only one oval.

	1	2	3	4	5	6	
Strongly Disagree	◯	◯	◯	◯	◯	◯	Strongly Agree

4. **I can facilitate use of student reasoning skills through inquiry-based activities.** *
Mark only one oval.

	1	2	3	4	5	6	
Strongly Disagree	◯	◯	◯	◯	◯	◯	Strongly Agree

5. **I can convert a traditional lab to an inquiry-based format.** *
Mark only one oval.

	1	2	3	4	5	6	
Strongly Disagree	◯	◯	◯	◯	◯	◯	Strongly Agree

CONSTRUCT 2: Perception of efficacy regarding inquiry-based teaching

6. **I feel that I could easily implement inquiry-based teaching in my own classroom.** *
Mark only one oval.

	1	2	3	4	5	6	
Strongly Disagree	◯	◯	◯	◯	◯	◯	Strongly Agree

7. **I feel that I could easily create inquiry-based lab activities for use in my own classroom.** *
Mark only one oval.

	1	2	3	4	5	6	
Strongly Disagree	◯	◯	◯	◯	◯	◯	Strongly Agree

8. **I feel that I could easily carry out inquiry-based lab activities in my own classroom.** *
Mark only one oval.

	1	2	3	4	5	6	
Strongly Disagree	◯	◯	◯	◯	◯	◯	Strongly Agree

9. **I feel that I could easily facilitate use of student reasoning skills through inquiry-based activities.** *
Mark only one oval.

	1	2	3	4	5	6	
Strongly Disagree	◯	◯	◯	◯	◯	◯	Strongly Agree

10. **I feel that I could easily convert a traditional lab to an inquiry-based format.** *
Mark only one oval.

	1	2	3	4	5	6	
Strongly Disagree	◯	◯	◯	◯	◯	◯	Strongly Agree

CONSTRUCT 3: Attitude toward using inquiry-based teaching

11. **Students should be provided with the purpose for a lesson as it begins** *

Mark only one oval.

	1	2	3	4	5	6	
Strongly Disagree	⬭	⬭	⬭	⬭	⬭	⬭	Strongly Agree

12. **It is better for science instruction to focus on ideas in depth, even if that means covering fewer topics** *

Mark only one oval.

	1	2	3	4	5	6	
Strongly Disagree	⬭	⬭	⬭	⬭	⬭	⬭	Strongly Agree

13. **At the beginning of instruction on a science idea, students should be provided with definitions for new scientific vocabulary that will be used** *

Mark only one oval.

	1	2	3	4	5	6	
Strongly Disagree	⬭	⬭	⬭	⬭	⬭	⬭	Strongly Agree

14. **Hands-on/laboratory activities should be used primarily to reinforce a science idea that the students have already learned** *

Mark only one oval.

	1	2	3	4	5	6	
Strongly Disagree	⬭	⬭	⬭	⬭	⬭	⬭	Strongly Agree

15. **Teachers should explain an idea to students before having them consider evidence that relates to the idea** *

Mark only one oval.

	1	2	3	4	5	6	
Strongly Disagree	⬭	⬭	⬭	⬭	⬭	⬭	Strongly Agree

APPENDIX B

CARD SORTING ACTIVITY

1
You, as a teacher, design a unit on drinking water by organizing lecture/discussion materials, and designing laboratory activities.

2
You, as a teacher, have your students first engage in laboratory activities, then follow-up with class discussion.

3
You have each student select a topic from a list that you provide. Working individually, the students may use the school library and/or the Internet as resources for writing a report on their selected topic.

4
As a means of assessment, you have students role-play the process of meiosis.

5
To help your students understand arthropod characteristics, you organize a series of stations. Each station contains representatives from a different class of arthropods.

6
You, as a teacher, decide the best way for students to learn about volcanoes is to have them build models of volcanoes.

7
In a weather unit, you have students take daily temperature and rainfall readings, as well as estimate wind speeds.

8
As a teacher, you organize a unit on drinking water by having students design their own investigations related to drinking water.

9
You, as teacher, begin a new unit by presenting basic background information and terminology before moving into the laboratory activities.

10
You, as a teacher, begin a pendulum unit by giving students strings and weights. By letting the students explore on their own, they will be able to discover which variable (length of string or mass) affects the number of swings per minute.

11
You, as a teacher, decide the best way for your students to learn about organic compounds is to organize the students into small groups. Each small group will present information on a different type of organic compound.

12
As a means of assessment, you give the students a multiple-choice exam.

13
As a teacher, you begin a unit on light by asking students to explain how they can see the writing on the chalkboard.

14
As a teacher, you decide the best way to teach photosynthesis is to design a well-organized series of lectures.

15
In a unit on evolution, you have students debate creation vs. evolution.

16
When designing laboratory activities, you include clear, easy to follow, step-by-step directions for the procedure.

17
As a chemistry teacher, you have the students memorize the first 20 elements of the periodic table.

18
In planning a unit, you collect a variety of activities for the students to do. You organize the unit by doing a different activity each day.

19
As a teacher, you have your students observe earthworms and generate questions about earthworm behavior. Each small group designs and carries out their own experiment to test a hypothesis related to the group's questions.

20
As a teacher, you begin a unit on plate tectonics by having your students read the chapter in the book.

APPENDIX C

REFORMED TEACHER OBSERVATION PROTOCOL (RTOP)

I. BACKGROUND INFORMATION

Name of teacher ____________________ Announced Observation? ____________________ (yes, no, or explain)

Location of class ____ (district, school, room)

Years of Teaching ______________ Teaching Certification ________________ (K-8 or 7-12)

Subject observed ____________________ Grade level ____________________

Observer ____________________ Date of observation ____________________

Start time ____________________ End time ____________________

II. CONTEXTUAL BACKGROUND AND ACTIVITIES

In the space provided below please give a brief description of the lesson observed, the classroom setting in which the lesson took place (space, seating arrangements, etc.), and any relevant details about the students (number, gender, ethnicity) and teacher that you think are important. Use diagrams if they seem appropriate.

Record here events that may help in documenting the ratings.

Time	Description of Events

III.	LESSON DESIGN AND IMPLEMENTATION	
		Never Occurred Very Descriptive
1)	The instructional strategies and activities respected students' prior knowledge and the preconceptions inherent therein.	0 1 2 3 4
2)	The lesson was designed to engage students as members of a learning community.	0 1 2 3 4
3)	In this lesson, student exploration preceded formal presentation.	0 1 2 3 4
4)	This lesson encouraged students to seek and value alternative modes of investigation or of problem solving.	0 1 2 3 4
5)	The focus and direction of the lesson was often determined by ideas originating with students.	0 1 2 3 4

IV.	CONTENT	
	Propositional knowledge	
6)	The lesson involved fundamental concepts of the subject.	0 1 2 3 4
7)	The lesson promoted strongly coherent conceptual understanding.	0 1 2 3 4
8)	The teacher had a solid grasp of the subject matter content inherent in the lesson.	0 1 2 3 4
9)	Elements of abstraction (i.e., symbolic representations, theory building) were encouraged when it was important to do so.	0 1 2 3 4
10)	Connections with other content disciplines and/or real world phenomena were explored and valued.	0 1 2 3 4
	Procedural Knowledge	
11)	Students used a variety of means (models, drawings, graphs, concrete materials, manipulatives, etc.) to represent phenomena.	0 1 2 3 4
12)	Students made predictions, estimations and/or hypotheses and devised means for testing them.	0 1 2 3 4
13)	Students were actively engaged in thought-provoking activity that often involved the critical assessment of procedures.	0 1 2 3 4
14)	Students were reflective about their learning.	0 1 2 3 4
15)	Intellectual rigor, constructive criticism, and the challenging of ideas were valued.	0 1 2 3 4

V. CLASSROOM CULTURE

Communicative Interactions	Never Occurred				Very Descriptive
16) Students were involved in the communication of their ideas to others using a variety of means and media.	0	1	2	3	4
17) The teacher's questions triggered divergent modes of thinking.	0	1	2	3	4
18) There was a high proportion of student talk and a significant amount of it occurred between and among students.	0	1	2	3	4
19) Student questions and comments often determined the focus and direction of classroom discourse.	0	1	2	3	4
20) There was a climate of respect for what others had to say.	0	1	2	3	4

Student/Teacher Relationships

21) Active participation of students was encouraged and valued.	0	1	2	3	4
22) Students were encouraged to generate conjectures, alternative solution strategies, and ways of interpreting evidence.	0	1	2	3	4
23) In general the teacher was patient with students.	0	1	2	3	4
24) The teacher acted as a resource person, working to support and enhance student investigations.	0	1	2	3	4
25) The metaphor "teacher as listener" was very characteristic of this classroom.	0	1	2	3	4

Additional comments you may wish to make about this lesson.

APPENDIX D

INTERVIEW QUESTIONS

1. Now that you have been through this whole experience (summer workshop and participating in a PLC where inquiry is the focus), what are the strengths of inquiry and what are the challenges?
    a. Has the experience changed your thinking or attitudes about this at all?
2. Tell me about your experiences teaching inquiry labs in your classroom?
3. What are your challenges and what are you proud of?
4. How did working with the other biology teachers in the PLC each week help support your efforts in teaching inquiry?

APPENDIX E

FREQUENCY OF HYPOTHESIS CODES

Category	Codes	Participants 1	2	3	4	5	6	Total
Teachers' attitudes and perceptions of inquiry-based pedagogy	Start with questions about nature	3	0	1	0	0	0	4
	Engage students actively	1	0	0	2	0	0	3
	Collection and use of evidence	0	0	0	1	1	0	2
	What students learn is influenced by their existing ideas	0	1	0	0	0	0	1
	Meet the interests, knowledge, understanding, abilities, and experience of the students	0	1	1	0	0	1	3
	Encourage and model the skills of scientific inquiry as well as the curiosity, openness to new ideas	3	1	0	1	1	2	8
	Teachers and students collaborate in the pursuit of ideas, and students often initiate new activities	0	0	0	2	0	0	2
	Community of science learners	0	0	0	1	0	0	1
	Students explain and justify their work to themselves and one another	0	0	0	1	0	0	1
Structure of the PD experience	Freedom to negotiate and adjust innovation through mutual adaptation	0	3	2	3	1	1	10
	Teachers having some prior knowledge of inquiry before the PD experience (Reinforcement and support for inquiry)	2	1	0	1	1	1	6
	Support from peers	2	1	0	2	0	0	5
	Opportunities for feedback and practice	1	0	0	0	0	0	1
	Chance to reflect, share and generalize learning	1	1	3	2	2	2	11
	Follow-up support and coaching	2	0	0	1	1	0	4
	Reshaping deeply ingrained assumptions and belief structures	0	1	0	0	1	0	2
	Critical self-reflections	0	0	0	4	1	1	6
	Participating in discourse	0	0	0	1	0	0	1
Challenges	Issues steering labs/getting imperfect results/giving up control	0	1	0	1	0	1	3
	Difficulty with lower-level/un-invested students	1	1	1	2	1	1	7
	Large class sizes	0	1	3	3	0	1	8
	Conflicting initiatives from district office administrators	0	2	1	0	0	0	3

APPENDIX F

CONSENT LETTER

Dear Science Teachers:

My name is Sarah Blechacz and I am a doctoral student in the Mary Lou Fulton Teachers College (MLFTC) at Arizona State University. I am working under the direction of Dr. Ray Buss, a faculty member in MLFTC. As members of the educational leadership and innovation program in the MLFTC at ASU, we are interested in investigating strategies that ensure high quality instruction for 21st Century classrooms that integrate inquiry into the curriculum. We are conducting a research study to examine the effectiveness of a professional development program aimed at encouraging and improving an inquiry-based approach to teaching science classes.

We are asking for your help, which will involve your participation in an interview. This will take about 20 minutes total.

Your participation in this study is voluntary. If you choose not to participate or to withdraw from the study at any time, there will be no penalty whatsoever.

The benefit to participation is the opportunity to reflect more carefully upon teaching methods. Interview results will also inform future iterations of the professional development program. Thus, there is potential to enhance the experiences that are provided to teachers and ultimately influence the use of inquiry-based teaching methods in science classrooms. There are no foreseeable risks or discomforts to your participation.

Your responses will be confidential. Results of this study may be used in reports, presentations, or publications but your name will not be known.

Please read the following consent statement and if you agree, please sign the attached recruitment/consent letter.

Consent Statement: I agree to participate in the interview being conducted. I understand the interview will take approximately 20 minutes to complete. I understand that my relationship with the school and interviewer will not be affected if I opt out of the interview. I am at least 18 years of age.

If you have any questions concerning the research study, please contact the research team—Ray Buss at raybuss@asu.edu or (602) 543-6343 or Sarah Blechacz at svetro@asu.edu.

Thank you,

Sarah Blechacz and Ray Buss (Co-PIs)
By signing here, I agree to participate in the interview and have it recorded.
Signature____ Date ______
If you have any questions about your rights as a participant in this research, or if you feel you have been placed at risk, you can contact Ray Buss at (602) 543-6343 or the Chair of the Human Subjects Institutional Review Board through the ASU Office of Research Integrity and Assurance at (480) 965-6788.